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THERMAL ENERGY STORAGE

Annual Report
January 1979 — March 1980

National Aeronautics and Space Administration
Lewis Research Center

Prepared for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Energy
Division of Energy Storage Systems

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National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Work performed for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Energy
Division of Energy Storage Systems
Washington, D.C. 20545
Under Interagency Agreement EC-77-A-31-1034

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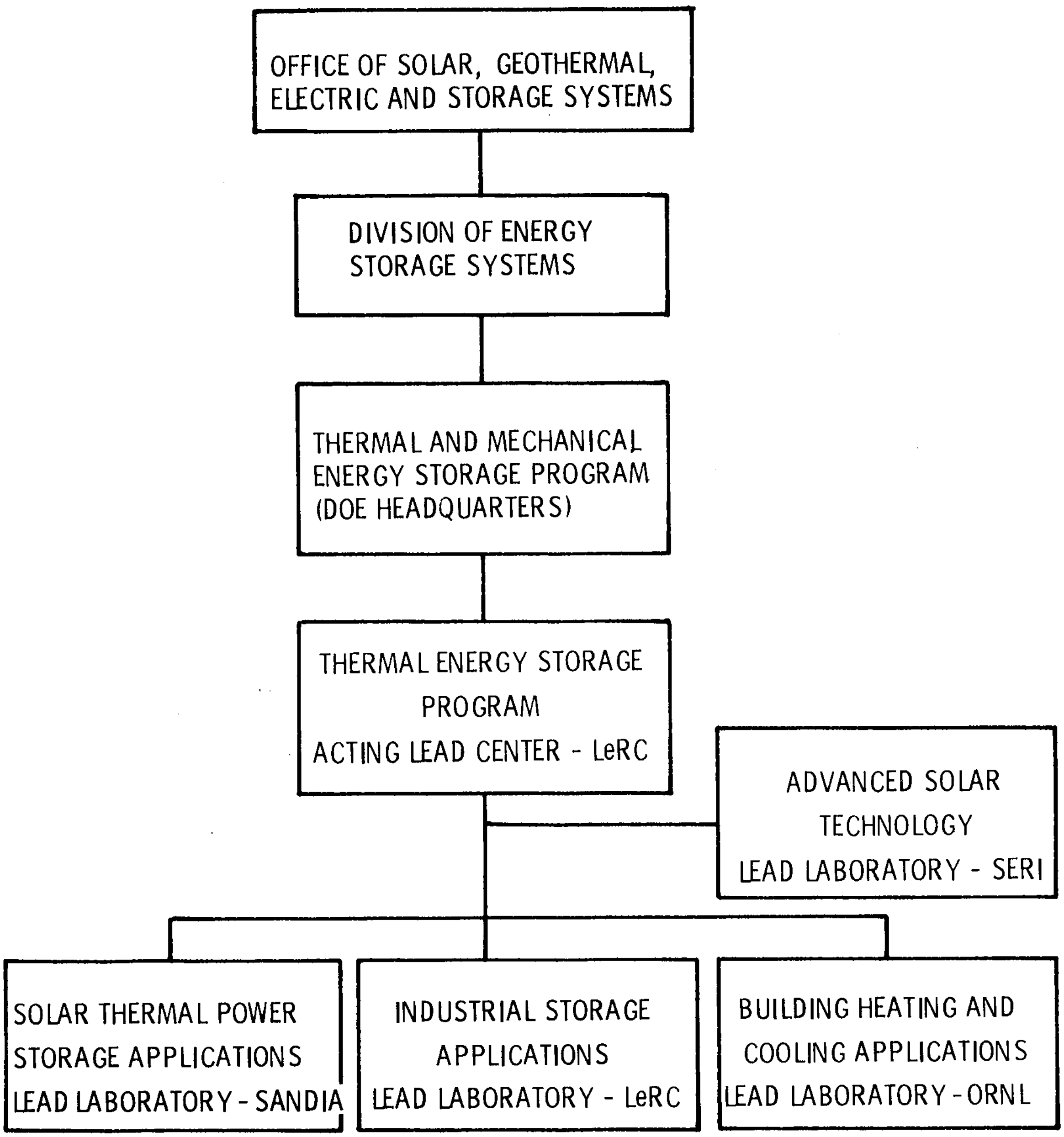
Preface

The DOE Division of Energy Storage Systems (DOE/STOR) is responsible for formulating and managing research and development in energy storage technology. Major responsibility for project management in selected areas has been shifted to the DOE national laboratories and other government agencies. NASA Lewis Research Center (LeRC) was given the primary responsibility for the development of high temperature sensible and latent heat storage technology. Project management responsibility was formally delegated to NASA under Interagency Agreement EC-77-A31-1034 on January 17, 1977. During FY 79 LeRC was given added responsibility in low temperature thermal storage applications related to industrial process and reject heat.

In accordance with DOE's emphasis on decentralizing program management functions, NASA was asked in May, 1979, to consider the possibility of LeRC assuming the lead center responsibility for DOE's Thermal Energy Storage Program (with the exception of aquifer storage) starting at the beginning of FY 1980. NASA reluctantly declined, in November, 1979, to take on additional responsibilities in the Program at LeRC and decided to phase-out LeRC's total involvement in the Program in FY 1980. While the NASA decision process was taking place, LeRC agreed to assume an "acting" lead center role to assist DOE in the planning and implementation of lead center activities.

This annual report (January, 1979 - March, 1980) was prepared as part of the reporting requirements under the interagency agreement, noted above. The report describes not only the planning/implementation of activities associated with the "acting" lead center management role but also the technical accomplishments pertaining to high temperature thermal energy storage subsystems.



DOE/STOR thermal energy storage program structure.

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Project Background

Near term oil savings, solar (inexhaustible) energy applications and dispersed energy systems are the primary activities being emphasized by the Department of Energy in their energy-saving and energy substitution missions. Thermal storage is an important factor in the success of these missions by correcting the supply/use mismatch that occurs in most energy delivery systems. Attractive applications include solar and conventional space heating/cooling, industrial process/waste heat recovery, and load shifting for coal, nuclear, and solar thermal electrical power generation.

Within DOE, responsibility for the development of reliable, efficient, and low cost thermal storage technologies has been delegated to the Division of Energy Storage Systems. Implementation of the Thermal Energy Storage Program under the direction of John Gahimer has been assigned to lead laboratories consisting of national laboratories and other government agencies. NASA Lewis Research Center (LeRC) was given the primary responsibility for the development of high temperature sensible and latent heat storage technology. Project management responsibility was formally delegated to NASA under Interagency Agreement EC-77-A31-1034 on January 17, 1977. During FY 79 LeRC was given added responsibility in low temperature thermal storage applications related to industrial process and reject heat.

In accordance with DOE's emphasis on decentralizing program management functions, NASA was asked to consider accepting the overall program management responsibility with LeRC as the lead center in thermal energy storage. However, considerations related to LeRC priorities and manpower constraints pertinent to DOE reimbursable programs, resulted in a decision to terminate LeRC participation in the DOE Thermal Energy Storage Program through an orderly transition to be completed in FY 80. During the phase-out period LeRC will continue to assume an "acting" lead center posture to assist DOE in the planning and implementation of lead laboratory activities. This annual report (January 1979 - March 1980) describes not only the planning/implementation of activities associated with the "acting" lead center management role but also the technical accomplishments pertaining to high temperature thermal energy storage subsystems.

The general objective of the Thermal Energy Storage Program is to develop the technology for cost and performance effective thermal energy storage systems for end-use application sectors. The technologies include all sensible and latent heat storage. Technologies for selected applications will be developed to the point of acceptance by the private sector or for systems integration and field testing by a DOE end-use Division. The Program's activities are accomplished principally through contracts within the private sector to provide early and effective transfer of technology. Government funds in support of this Program are provided by DOE. Activities are coordinated with complementary projects and tasks being pursued by DOE end-use Divisions and national laboratories, the Solar Energy Research Institute (SERI), the Electric Power Research Institute (EPRI), the Tennessee Valley Authority (TVA), the Naval Research Laboratory (NRL), and the Battelle, Pacific Northwest Laboratory (PNL).

The lead center and lead laboratory structure for the Thermal Energy Storage Program is shown in Figure (1). Major program elements reported herein as LeRC primary responsibilities are (1.0) Program Definition and Assessment, (2.0) Research and Technology Development, (3.0) Industrial Storage Applications. LeRC "acting" lead center management role pertains primarily to (4.0) Solar Thermal Power Storage Applications as well as (5.0) Building Heating and Cooling Applications.

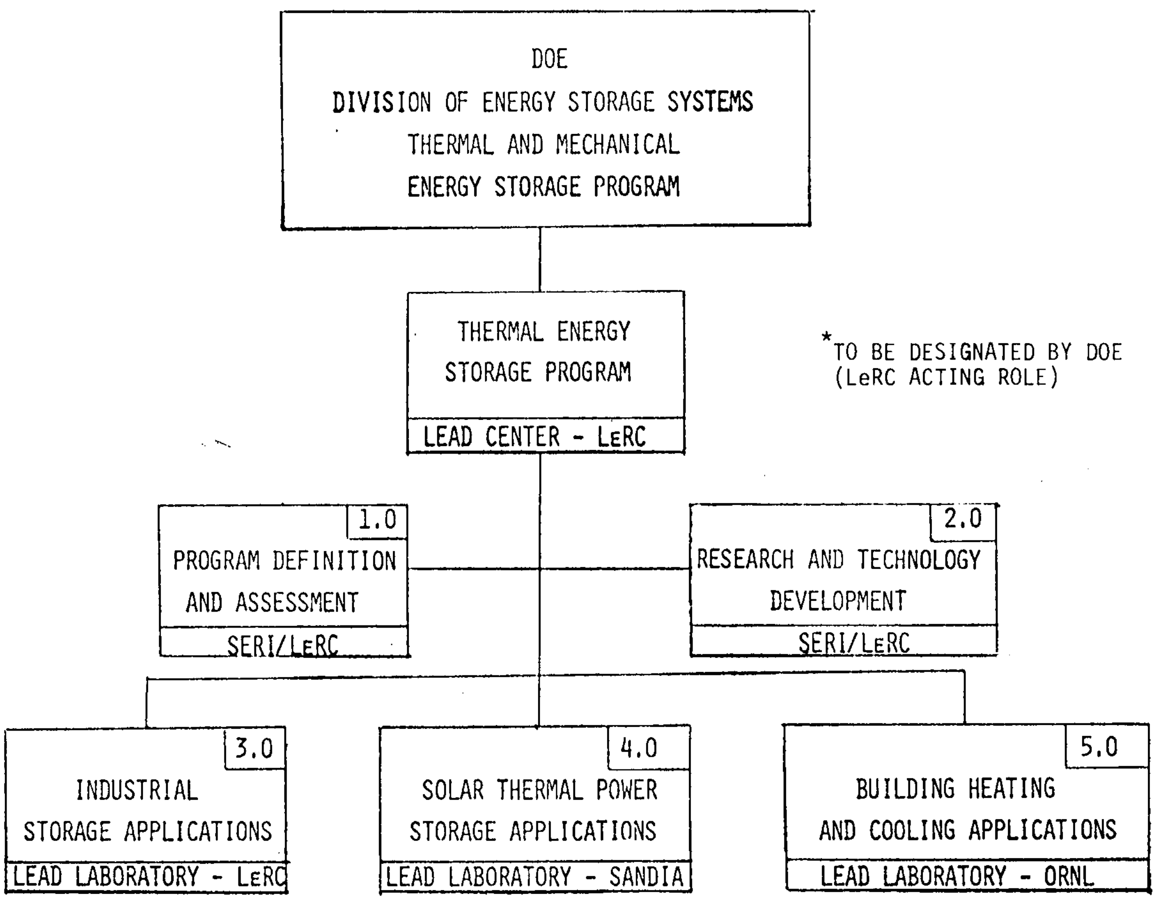


FIGURE 1. - THERMAL ENERGY STORAGE PROGRAM STRUCTURE.

A brief description of these program elements follows:

1.0 Program Definition and Assessment

An essential function related to management of the overall thermal energy storage program is that of program definition and assessment. The major emphasis in this activity is the implementation of a program-level assessment of thermal energy storage technology thrusts for the near and far term to assure an overall coherent energy storage program. Included is the identification and definition of potential new thermal energy storage applications, definition of technology requirements, appropriate system definition studies and identification of appropriate market sectors. This activity also includes the necessary coordination, planning and preparation associated with program reviews, workshops, multi-year plans and annual operating plans for the major lead laboratory tasks. SERI assessment tasks will be coordinated and integrated into this activity. LeRC activities in this area will be terminated and existing planning transferred to the DOE designated lead center in FY 80.

2.0 Research and Technology Development

This task will provide for an advanced technology base which will lead to improved thermal energy storage concepts and designs for existing baseline storage systems. Generic, high risk technologies will be evaluated and appropriate technology development undertaken. A close SERI interface will be established and maintained to coordinate and select those technologies which offer a significant advancement based on the results of current SERI studies. Included in this activity are the technical monitoring requirements associated with several current development contracts and the management of the LeRC in-house thermal energy storage tests. Existing contracts will be completed during FY 80. No new tasks will be initiated.

3.0 Industrial Storage Applications

The major tasks in this program element are the implementation of a technology demonstration for the food processing industry, the development and technology demonstration for selected near-term, in-plant applications and the development and technology demonstration for advanced industrial applications. These tasks will be supported by an on-going system studies activity which will assess near-term, in-plant applications, solar applications, and heat transport requirements. An important adjunct to this activity is the continued implementation of technology transfer through information collection and dissemination. Current procurement activity will be completed after which contract technical management will be transferred to a DOE designated lead center or laboratory in FY 80.

4.0 Solar Thermal Power Storage Applications

Plans have been developed with DOE for a comprehensive advanced thermal energy storage technology and development program in FY 80-85 covering all solar thermal large and small power systems applications. Major thrusts in this application area will be implemented by DOE designated lead laboratories with overall program management to be the responsibility of a DOE designated lead center. Major emphasis will be given to advanced thermal storage for molten salt, central receiver systems and the organic sensible heat distributed receiver systems to support application areas such as Barstow and Shenandoah. SERI tasks related to supporting research and technology for the thermal storage program are an integral part of this activity. Management activity related to these tasks will be transferred to the DOE designated lead center in FY 80.

5.0 Building Heating and Cooling Applications

Plans are being developed for a comprehensive thermal energy storage technology and development program covering building heating and cooling applications in the residential and commercial sectors. Primary emphasis is on the "customer side of the meter" storage applications to provide for utility load management. Development and demonstration of improved and advanced thermal storage subsystems for space conditioning in solar applications are included in the overall program goals. Management activity related to these tasks will be transferred to the DOE designated lead center in FY 80.

PROJECT MILESTONES /MAJOR ACCOMPLISHMENTS

ELEMENT	EXECUTION BY	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84
1.0 PROGRAM DEFINITION & ASSESSMENT	**/SERI		1		2		
2.0 RESEARCH & TECHNOLOGY DEVELOPMENT	**/SERI		3		4		
3.0 INDUSTRIAL STORAGE APPLICATIONS	LeRC/**		5	6	7		8
4.0 SOLAR THERMAL POWER STORAGE APPLICATIONS	SANDIA LL			9	10	11	
5.0 BUILDING HEATING & COOLING APPLICTIONS	ORNL		12, 13				

1. AWARD CONTRACT FOR PROGRAM ANALYSIS AND PLANNING ASSESSMENT
2. INITIATE SECOND PHASE OF PROGRAM ANALYSIS AND PLANNING ASSESSMENT
3. COMPLETE METAL ALLOY PROPERTY MEASUREMENT AND CONTAINMENT COMPATIBILITY FOR HIGH TEMPERATURE TES CONCEPTS
4. COMPLETE LABORATORY DEVELOPMENT FOR ADVANCED STORAGE SYSTEM APPLICATIONS CONCEPTS
5. AWARD MULTIPLE CONTRACTS FOR INDUSTRIAL DEMONSTRATIONS FOR NEAR-TERM APPLICATIONS
6. COMPLETE PAPER/PULP THERMAL ENERGY STORAGE TECHNOLOGY TRANSFER
7. COMPLETE FOOD PROCESSING INDUSTRY DEMONSTRATION
8. COMPLETE NEAR-TERM INDUSTRIAL STORAGE DEMONSTRATION
9. COMPLETE SRE*DESIGN, TESTING OF STORAGE FOR MOLTEN SALT COOLED RECEIVERS FOR SOLAR INDUSTRIAL APPLICATIONS
10. COMPLETE SRE*DESIGN, TESTING FOR SMALL COMMUNITY SYSTEMS
11. COMPLETE SRE*DESIGN, TESTING FOR SHENANDOAH RETROFIT
12. RELEASE RFP ON COOLING STORAGE FOR RESIDENTIAL LOAD MANAGEMENT STORAGE SYSTEMS
13. RELEASE RFP ON IMPROVED HEATING FOR RESIDENTIAL/COMMERCIAL LOAD MANAGEMENT STORAGE SYSTEMS

*SRE: SYSTEM RESEARCH EXPERIMENT

**DOE DESIGNATED LEAD CENTER AND/OR LEAD LABORATORY

FIGURE 2. - SCHEDULE SUMMARY.

The Schedule Summary (Figure 2) identifies the major milestones related to the lead center and lead laboratory activities. The program's planned major activities are directed toward thermal storage applications for the industrial, solar thermal power and building heating and cooling sectors. Elements 1.0, 2.0 and 3.0 are those in which LeRC would have played a major role had LeRC retained the lead center role. However, with the decision to terminate thermal energy storage activities, this reporting period became, for LeRC, a period of transition during which lead center and lead laboratory tasks have been in the process of transfer. DOE Headquarters is assuming the lead center responsibility and ORNL was assigned the Industrial Storage Lead Laboratory task in early March 1980. As a consequence of the NASA decision to terminate thermal storage activities the milestones in elements 1.0, 2.0 and 3.0 are not all directly applicable.

Element 1.0 has been deferred until DOE Headquarters is adequately staffed to implement this activity. Element 2.0 milestone 3 will be completed by LeRC, however, milestone 4 is subject to future decisions. Element 3.0 milestone 5 will be accomplished by LeRC late in FY 80 after which responsibility will be transferred to ORNL. The remaining milestones in Element 3.0 will be subject to ORNL/DOE management decisions. Elements 4.0 and 5.0 are not directly controlled by LeRC and, therefore, will not be discussed here.

Major accomplishments toward achieving the above milestones are itemized below per the respective elements:

1.0 PROGRAM DEFINITION AND ASSESSMENT

- For electric utility applications, the GE task "Conceptal Design of Thermal Energy Storage Systems for Near Term Electric Utility Applications" was completed in March 1979. A public review was held in April 1979 and a final report published in July 1979.
- LeRC assumed an acting lead center role and implemented coordination meetings with thermal energy storage program lead laboratories in May 1979.
- W. Masica (LeRC) participated in the International Assembly on Energy Storage held in Yugoslavia in May 1979.
- DOE/STOR was informed on November 21, 1979 that NASA will terminate thermal energy storage activities through an orderly transition to be completed during FY 1980.
- The DOE/STOR Annual Thermal Energy Storage Program Review was held at Tyson Corner's, Virginia in December, 1979. This activity was organized by LeRC.

2.0 SUPPORTING RESEARCH AND TECHNOLOGY

- A University of Delaware grant for laboratory studies of metal alloy thermal storage media was extended for one year in August 1979.
- A contract to perform laboratory studies of high temperature carbonates was awarded to IGT in August 1979.
- Final results of MRI's TES fluidized bed analysis indicate that for selected, near-term industrial applications (cement, electric arc furnaces) the fluidized beds are only marginally competitive.
- A technical report describing the LeRC in-house testing and engineering evaluation of prototype latent heat (sodium hydroxide) storage module was published.

3.0 INDUSTRIAL STORAGE APPLICATIONS

- An RFP for technology transfer in the paper and pulp industry was released in June 1979. Subsequent proposal evaluation led to a contract award to Howard Edde, Inc., Seattle, Washington in February 1980.

3.0 INDUSTRIAL STORAGE APPLICATIONS - Cont.

- An RFP for a noncompetitive procurement was released to H. J. Heinz Company, Pittsburgh, Pennsylvania for a technology demonstration. This task will be transferred to ORNL for contract award and implementation.
- The RFP for "Development/Demonstration of TES in Industrial Applications" was released on February 29, 1980. This $11M procurement will be transferred to ORNL after contract award in late FY 80.
- R. Duscha (LeRC) presented a paper entitled "The Role of Thermal Energy Storage in Industrial Energy Conservation" at the 1979 Conference on Industrial Energy Conservation Technology, April 1979 in Houston, Texas.
- R. Duscha presented a paper entitled "Industrial Thermal Storage Applications" at the Second Franco-American Conference on Industrial Energy Conservation held in Washingon, DC in February 1980.

4.0 SOLAR THERMAL POWER SYSTEMS APPLICATIONS

- L. Gordon (LeRC) served as chairman of the Storage for Process Heat Applications Panel, Solar Energy Storage Options Workshop held in San Antonio, Texas, March 1979.
- Grumman, Honeywell and IGT participated in a contractor's status review held at LeRC in March 1979. Participants included NASA Headquarters, JPL, and SLL personnel.
- J. Calogeras (LeRC) presented a storage technology status review for Solar Thermal Power Systems at the Semi-Annual DOE/CST Advanced Technology Meeting in Long Beach, California in June 1979.
- The DOE/STOR multi-year plan "Thermal Energy Storage for Solar Thermal Applications" was reviewed for DOE/STOR in September 1979. The plan presents a coordinated DOE/STOR/CST effort to provide storage subsystems.
- E. Furman (LeRC) presented a paper on thermal storage at the Solar Industrial Process Heat Conference held in Oakland, California in November 1979.
- Honeywell completed tests of their Reflux Boiler (water/molten salt) active heat exchange module in December 1979. Success was limited due to the formation of unstable compounds (hydrated salts).

4.0 SOLAR THERMAL POWER SYSTEMS APPLICATIONS - Cont.

- A ground breaking ceremony for the 2 MWH (th) Energy Storage Boiler Tank was held on January 4, 1979 at the Naval Research Laboratory, Washington, DC.

5.0 BUILDING HEATING AND COOLING

- LeRC jointly formulated with ORNL the project structure for the BHAC based on DOE/STOR restructuring of aquifer and low temperature industrial application areas.

PROJECT ELEMENT SUMMARIES

- O BACKGROUND
- O APPROACH
- O ACCOMPLISHMENTS
- O ISSUES
- O ACTIVITY SCHEDULE

ELEMENT 1.0

PROGRAM DEFINITION AND ASSESSMENT

BACKGROUND:

An essential function related to management of the overall thermal energy storage program is that of program definition and assessment. The major emphasis in this element is the implementation of a program level assessment of thermal energy storage technology thrusts for the near and far term to assure an overall coherent energy storage program. Included is the identification and definition of potential new thermal energy storage applications, definition of technology requirements, appropriate system definition studies and identification of appropriate market sectors. This element also includes the necessary coordination, planning and preparation associated with program reviews, workshops, multi-year plans and annual operating plans for the major lead laboratory tasks.

APPROACH:

PROGRAM PLANNING AND MANAGEMENT

The Thermal Storage Program develops reliable, efficient, inexpensive storage technologies to support other DOE or private sector end-users in their substitution and energy savings missions. Within DOE this is accomplished by technology transfer agreements between STOR and the respective end-use divisions as shown in Figure 3.

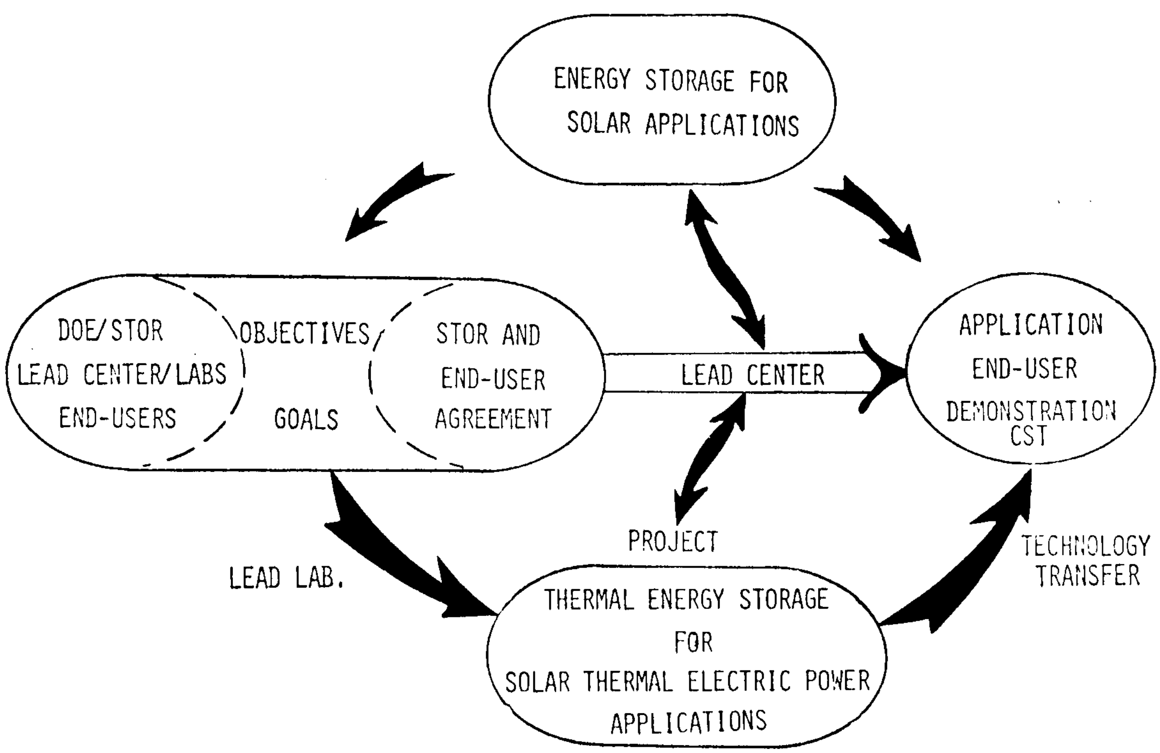


Figure 3. - Program definition and assessment flow chart program.

The lead center is responsible for ensuring that the milestones, resources, and technology transfers are accomplished. Initially, an energy storage program assessment is performed for a particular application area. If this assessment indicates that thermal energy storage is competitive with respect to other storage technologies (batteries, flywheels, etc.) then the objective/goals can be defined for a project area. The lead laboratory provides the necessary management to implement the project and provide the necessary technology for transfer to the end-user.

Lead laboratory project structure generally takes a form similar to that shown in Figure 4. System studies are application oriented and consist of concept identification, technoeconomic assessments, and conceptual design studies. Concept development activities include development of storage concepts to the point of establishing the technical feasibility and assessing the concepts based on general application requirements. Establishing technical feasibility involves both concept feasibility studies and small-scale laboratory experiments.

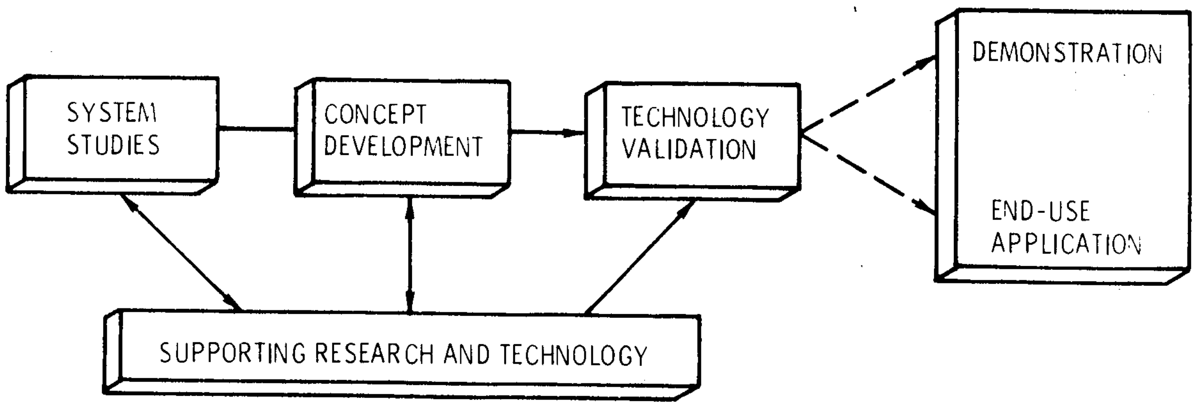


Figure 4. - Lead laboratory project structure.

The subsystem development phases culminate with technology readiness or technology validation for the storage subsystem. Activities include subsystem definition, engineering development, and subscale research experiments (SRE's). Throughout these various project phases continuous efforts are directed toward generic advanced technology and exploratory research studies thus providing a supporting research and technology base.

Primary results of program planning and management are documented in three documents: (1) Interagency Agreement (IAA), (2) Annual Operating Plan (AOP), and (3) Monthly Management Information and Contract Status (MICS) reports. The FY 79 IAA Amendment 3 was signed in February, 1979 for $1,800.000. The FY 79 AOP further delineated the breakdown of resources to specific tasks. The status of these tasks, noting accomplishments, impact items, and forward actions is reported in the MICS.

The draft FY 80 AOP, although required to be submitted by September 1, 1979, was not released to DOE until December 1979. This delay was a bilateral agreement pending NASA's decision pertaining to the DOE request for LeRC to become the lead center for thermal storage.

PROJECT ASSESSMENT

During this reporting period, specific project assessments focused on the completion of system studies for "Peak Following Thermal Storage for Steam Electric Power". For near-term utility applications it was felt that thermal energy storage could be easily "retrofitted" to existing power plants. However, an earlier project assessment by Bechtel concluded that high capital costs and long retrofit downtimes negated the use of thermal energy storage. On the positive side, it was recommended that thermal energy storage might be attractive for "new construction" coal and nuclear power plant application. A second assessment completed in FY 79 for New Plant Thermal Energy Systems was performed by General Electric.

GENERAL ELECTRIC
(DEN3-12)

This "new plant" assessment was quite extensive and examined some 50 plus technologies applicable to thermal energy storage subsystems. From this matrix, twelve (12) concepts were selected for a detailed technoeconomic assessment as shown in Figure 5.

TYPE	MEDIUM	FEATURE	UTILIZATION
SENSIBLE HEAT	WATER	PRESTRESSED CAST-IRON VESSEL	FWH, SG
		PRESTRESSED CONCRETE AND WELDED STEEL PRESSURE VESSELS	FWH, SG
		CONCRETE-SUPPORTED CAVERN TANK	SG
		AIR-SUPPORTED CAVERN TANK	FWH
		AIR-SUPPORTED CAVERN TANK - STEEL LINED	SG
		AQUIFER	FWH
	WATER/STEEL	HEAVY WALLED STEEL CYLINDERS	FWH, SG
	OIL	DUAL TANKS	FWH
	OIL AND ROCK	THERMOCLINE TANK	FWH, SG
	OIL/MOLTEN SALT	TWO STAGE, DUAL OR THERMOCLINE TANK	SG
	MOLTEN SALT	DUAL TANKS	SG
PHASE CHANGE	SALT EUTECTIC	DIRECT CONTACT SYSTEM	SG

FWH - FEEDWATER HEAT
SG - STEAM GENERATION

Figure 5. - New plant TES assessment for utility applications.

Conceptual designs of four selected TES system concepts were integrated into conventional base loaded plant designs. These concepts, as indicated on Figure 5, were as follows:

a. A dual media, sensible heat, thermal energy storage integrated with a high sulfur coal power plant and supplying steam to a separate peaking power conversion system.

b. An underground, high temperature water, thermal energy storage integrated with a high sulfur coal power plant and supplying steam to a separate peaking power conversion system.

c. An above ground, high temperature water, thermal energy storage integrated with a Pressurized Water Reactor power plant and supplying boiler feedwater preheat.

d. A dual media, sensible heat, thermal energy storage integrated with a Pressurized Water Reactor power plant and supplying boiler feedwater preheat.

The bottom line of this assessment concluded that load leveling thermal storage is only marginally competitive with baseload, coal fired, cycling plants.

How the results of the Bechtel and General Electric assessments affected the "Peak Following Thermal Storage for Steam Electric Power" project is graphically shown in Figure 6. Based on the "negative" and "marginally competitive" assessments, the planned concept development and technology validation phase of the project were redefined. Future development activities for utilities will be directed toward compressed air energy storage (CAES) integrated with thermal energy storage.

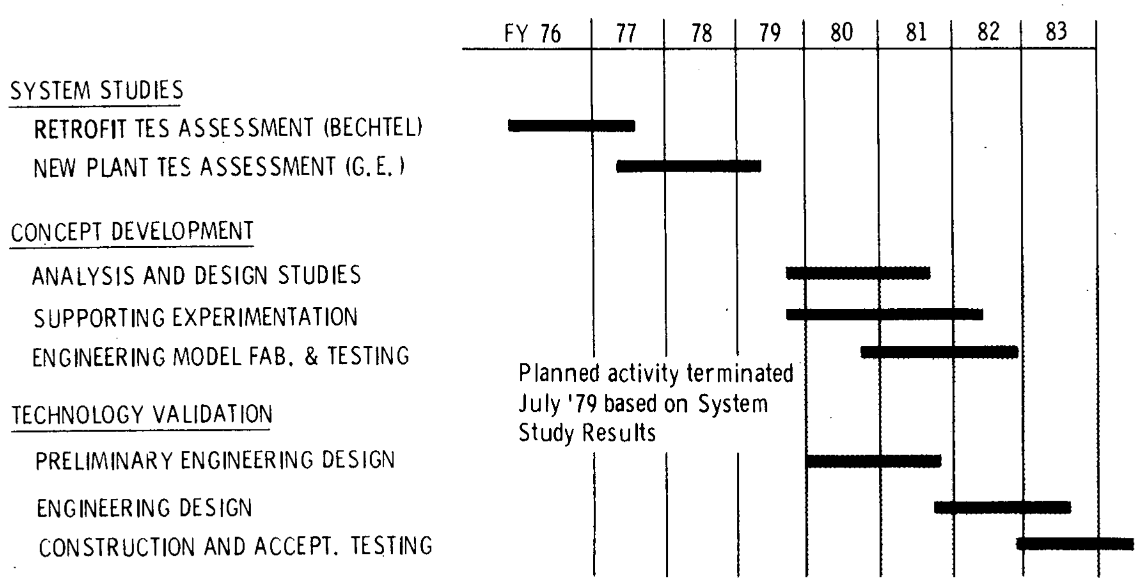


Figure 6. - Project schedule for peak following TES.

As acting lead center, consideration was given to the overall program assessment and its relationship to the DOE Division, the lead center, and responsible lead laboratory. This assessment (for BHAC, INDUS, UTILITY, etc.) is shown in Figure 7 as the "shaded" activity. As part of this assessment, a competitive contract was planned (later cancelled because of NASA's decision not to assume lead center role) and would have consisted of the following:

a. Conducting a supporting analysis of the current program areas with major emphasis on solar thermal applications. Storage alternatives will be identified along with technology requirements. Value comparisons will be performed and commercialization requirements will be identified.

b. Identifying new applications and their technology requirements. New storage concepts defined and economic evaluation will be performed. Suitable demonstrations will be recommended in those application areas offering potential for substantial ROI.

c. Assuring overall integration and coordination of thermal storage developments with the appropriate DOE end-use divisions. This task will include assessments of technical progress, coordination of development goals, and milestones. Particular attention will be given to the impact of environmental requirements.

INFORMATION DISSEMINATION

Previous reviews of the Thermal Energy Storage Program have been reported as Contractors Information Exchange Meetings I, II and III. The format for the fourth annual meeting (FY 79) was changed to reflect a year of transition and overall program planning for thermal storage; hence, the Thermal Energy Storage Program Review Meeting. As acting lead center, Lewis Research Center hosted the meeting at the Holiday Inn, Tyson Corners, Virginia on December 3-5, 1979. Proceedings have been prepared for April, 1980 distribution and will contain the respective project area overviews and selected presentations on specific technical and/or economics areas of concern. To provide a complete compendium of all of the on-going contracted activities in Thermal Energy Storage, brief summary reports, solicited from each contractor, were also incorporated as part of the Proceedings.

LeRC participation in various energy storage workshops was also a major activity in this area.

Solar Energy Storage Options, an intensive workshop on thermal energy storage for solar heating and cooling, was held in March, 1979, in San Antonio, Texas. The workshop, which attracted participants from throughout the U.S., Canada, and a number of other nations, focused on six major subject areas: Annual Storage for Building Heating and Cooling, Solar Energy-Electric Heat Pump Systems, Storage for Process Heat Applications, Storage in Building Materials for Heating and Cooling, Central Storage for Building Heating, and Central Storage for Building Cooling. Lewis was responsible for Storage for Process Heat Application session and the associated panel discussions/reports.

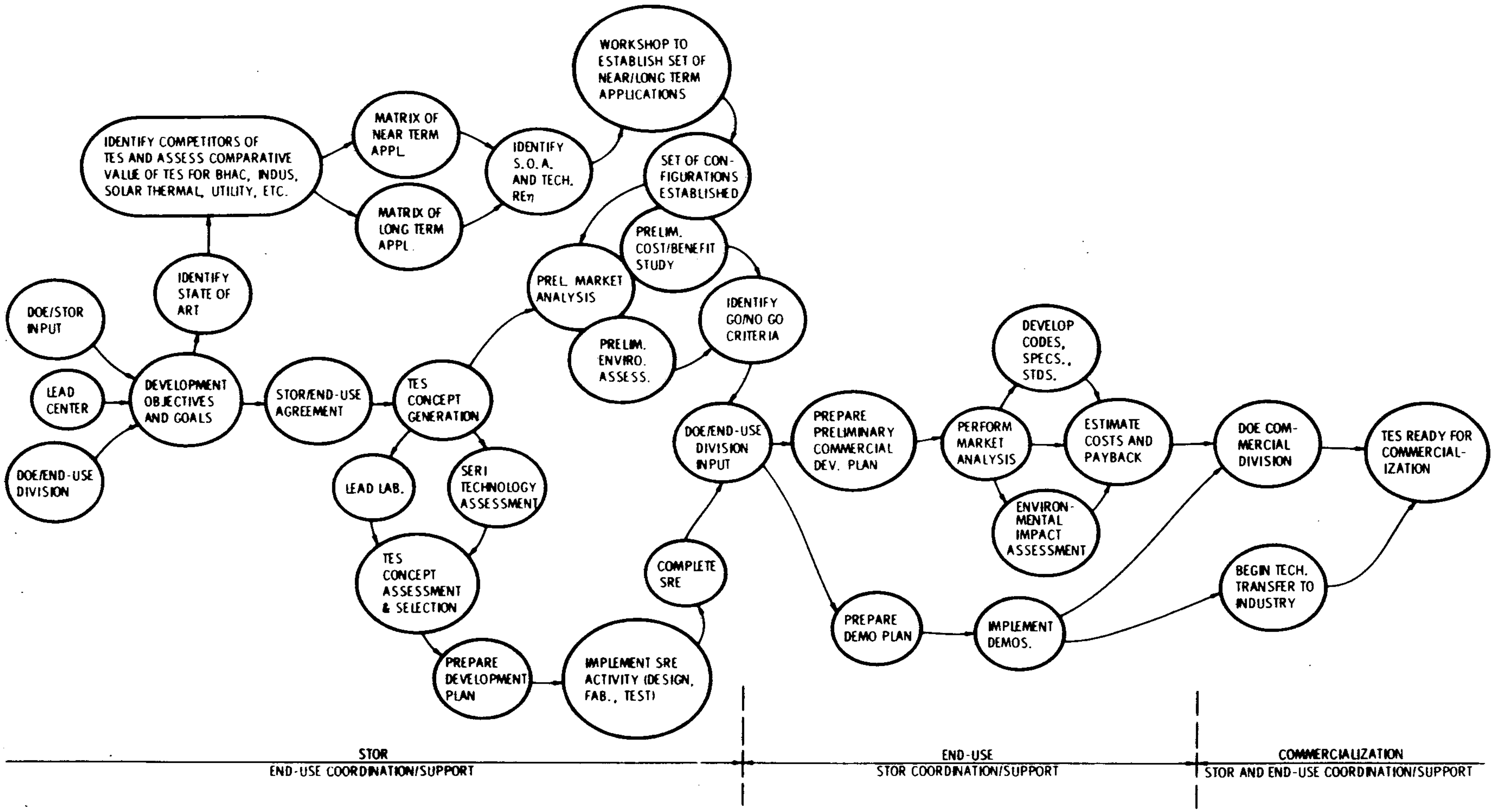


Figure 7. - Program definition, planning, and system assessment.

ACCOMPLISHMENTS

- Completed the General Electric assessment of "Thermal Energy Storage for Peak-Following Utility Applications". Based on the economic evaluation of being marginally competitive with coal fired cycling plants, the planned (next phase) field test project was cancelled. (April, 1979)

- Chaired committee on Storage for Process Heat at the Solar Energy Storage Options Workshop in San Antonio, Texas (March, 1979).

- Participated in the "Solar Applications Analysis for Energy Storage" being performed for STOR/TEA Branch by Aerospace (September, 1979 start).

- Submitted draft FY 80 Annual Operating Plan which transfers all LeRC "acting" lead center functions and lead laboratory activities back to DOE/STOR or STOR designee by the end of FY 80 (Dec. 79).

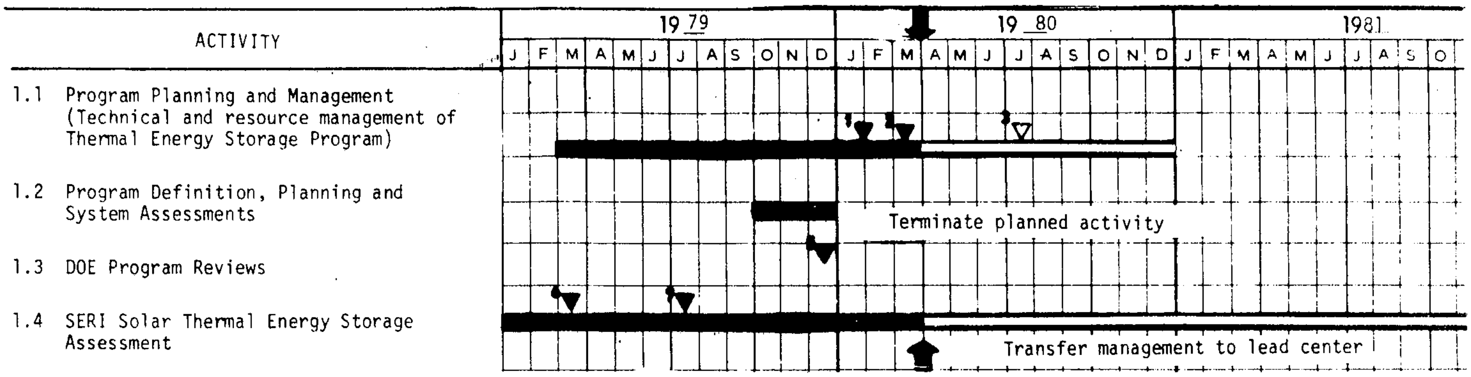
- Hosted the DOE/STOR "Thermal Energy Storage Program Review" meeting at Tyson Corners, Virginia (December, 1979).

- Prepared for April, 80 distribution of the 600 plus page, "Proceedings of the Thermal Energy Storage Program Review" (Feb. 80).

ISSUES

- In accordance with DOE's emphasis on decentralizing program management functions, NASA was asked in May, 1979, to consider the possibility of LeRC assuming the lead center responsibility for DOE's Thermal Energy Storage Program (with the exception of aquifer storage) starting at the beginning of FY 1980. Due to manpower constraints and LeRC priorities pertinent to DOE reimbursable programs, NASA reluctantly declined, in November, 1979, to take on additional responsibilities in the Program in FY 1980. While the NASA decision process was taking place, LeRC agreed to assume an "acting" lead center role to assist DOE in the planning and implementation of lead center activities. Thus, FY 1980 is considered as a transition year during which all of the Thermal Energy Storage Program activities for which LeRC has responsibility, including "acting" lead center activities, will be transferred to a DOE designated lead center or laboratory.

ACTIVITY SCHEDULE



1. Annual Operating Plan Submittal to DOE
2. DOE Approval of AOP
3. Annual Report
4. SOW Preparation Complete
5. Program Review
6. Thermal Energy Storage for Solar Applications: An Overview, Mar. 79
7. Low Temperature TES, SOA Survey, July 1979

▽	Milestones
▽1	Rescheduled Activity
▼	Completed Activity
S	Establish SEB
r	Release RFP
a	Award Contract
P	Publish Report
SS	Sole Source Procurement
CP	Competitive Procurement
IAA	Interagency Agreement
DHP	DOE Headquarters Procurement
PA	Planning Activity

2.0 RESEARCH AND TECHNOLOGY DEVELOPMENT

BACKGROUND

During FY 79-80, NASA-Lewis Research Center has served as the lead center for DOE/STOR's Thermal Energy Storage Program. The activities of the lead center include coordinating a research and technology development program and managing several of the efforts within that program. The program has three objectives. The first objective is to establish advanced technologies for TES systems to improve upon baseline system performance and/or lower storage system costs. The second objective is to resolve problems that are generic to several applications. Typical examples of these problems are requirements for improved heat transfer and identification of suitable storage media or appropriate containment materials. The third objective is to provide any support required for the development of baseline TES systems.

Many of the projects, especially those that are focused on a specific application, are originated at and implemented by the lead laboratories. The projects may be conducted by a private organization on contract to the lead laboratory or may be conducted in-house. The functions of the lead center are to coordinate the various projects between the organizations involved, to recommend projects that are focused on a specific application, and to conduct investigations that address issues generic to several applications.

APPROACH

The research and technology development program consists of several types of activities. New storage concepts are identified and then assessed to determine performance and cost potentials and identify required technology developments. Materials that are candidates for TES media are investigated to determine heat transfer and corrosion characteristics. Proof-of-concept experiments are conducted for the concepts that have the most potential. Another activity is the engineering evaluation of prototype storage modules to evaluate present technology. There are two characteristics that are common to most of these activities. The activities are relatively short-term projects and usually include laboratory or bench scale experiments.

The activities being managed by LeRC are shown below:

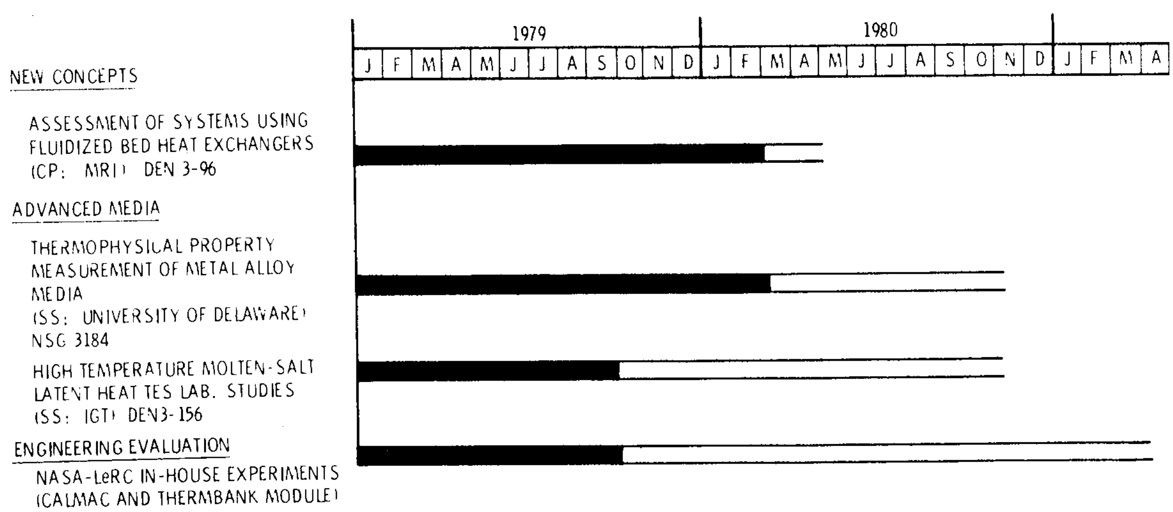


Figure 8. - Research and technology flow chart.

NEW CONCEPT ASSESSMENTS

The object of this activity is to identify and select promising advanced concepts and to determine what technology developments are required for the concept. An assessment study determines what applications are appropriate and assess several variations of a concept to determine the most promising configuration. The study would include an evaluation to determine potential energy savings that would result from use of the selected concepts. The assessment study would evaluate the technology development required to make construction of a full-scale system practical and conclude with recommendations about the technical and economic feasibility of selected concepts, the technical developments required, and a proposed plan to develop the concept if warranted.

The assessment emphasized during the report period pertained to the concept of using fluidized beds as a combined low cost thermal storage and highly efficient heat exchanger subsystem.

The fluidized bed provides for good heat transfer between a gas and a tube bank since solid particle thermal contact takes place as well as high particle mobility. The transfer coefficients are somewhere between gas and liquid values for the same velocities of flow. The high particle mobilities, however, mean that the top and bottom of a fluidized bed will, in general, be equal. In order to have a temperature distribution in a fluidized bed, it is necessary to either operate at the ragged edge of fluidization (essentially unstable) or partition the bed so as to inhibit particle mobility. This staging concept adds considerably to the complexity of construction and requires development work for the particular geometries and particles chosen. The advantages of a fluidized bed heat exchanger, even though staging is required, are that the solid particles are mobile and can readily be transferred from one bed to another or to a storage vessel. In addition, the particle mobility eliminates the thermal stress limitation which is frequently encountered with either cored brick or pebble bed heaters.

However, as with any heat exchanger/storage/application combination, there exists technological uncertainties and potential component/system integration problems which must be analyzed before cost benefits can be accurately assessed. The need for this identification and the techno-economic assessment of a viable heat exchanger/storage system becomes the justification for this proposed effort.

MIDWEST RESEARCH INSTITUTE
(DEN 3-96)

Midwest Research Institute was awarded the program to provide and parametrically analyze the operating characteristics and the economics of selected thermal energy storage applications utilizing fluidized bed heat exchangers. Specific task objectives were: (1) the definition of potential fluidized bed concepts for thermal energy storage applications, and (2) a techno-economic evaluation of selected heat exchanger/storage/ application systems.

In Task I, Application Identification, Concept Definition and Integration the MRI recommended six fluidized bed applications, the majority of which used the multi-staged beds. These applications were as follows:

1. Cement Plant - Rotary Kiln/Clinker Cooler
2. Steel Plant - Electric Arc Furnace
3. Copper Smelting - Reverberatory Furnace/Converter
4. Steel Plant - Iron Ore Sintering
5. Steel Plant - Dry Quench Coke
6. Solar Brayton Power Plant - Solar Receptor Supplement

From these six applications, the cement plant and the steel plant (electric arc furnace) were selected as the two applications for the detailed Task II Technical Analysis and Economic Evaluation. Both of these applications would utilize the multi-stage fluidized bed thermal energy storage subsystem.

MRI's assessment has been completed and, the fluidized bed TES applications (electric arc furnace, cement kiln) were found to be marginally competitive for near-term, baseline systems (e.g. Element 3.0 Industrial Storage Applications) based on utility rate structure/incentives. It was also recommended that fluidized beds for advanced applications (solar thermal) should be assessed in the near future based on systems identified as part of Element 4.0 (Solar Thermal Applications).

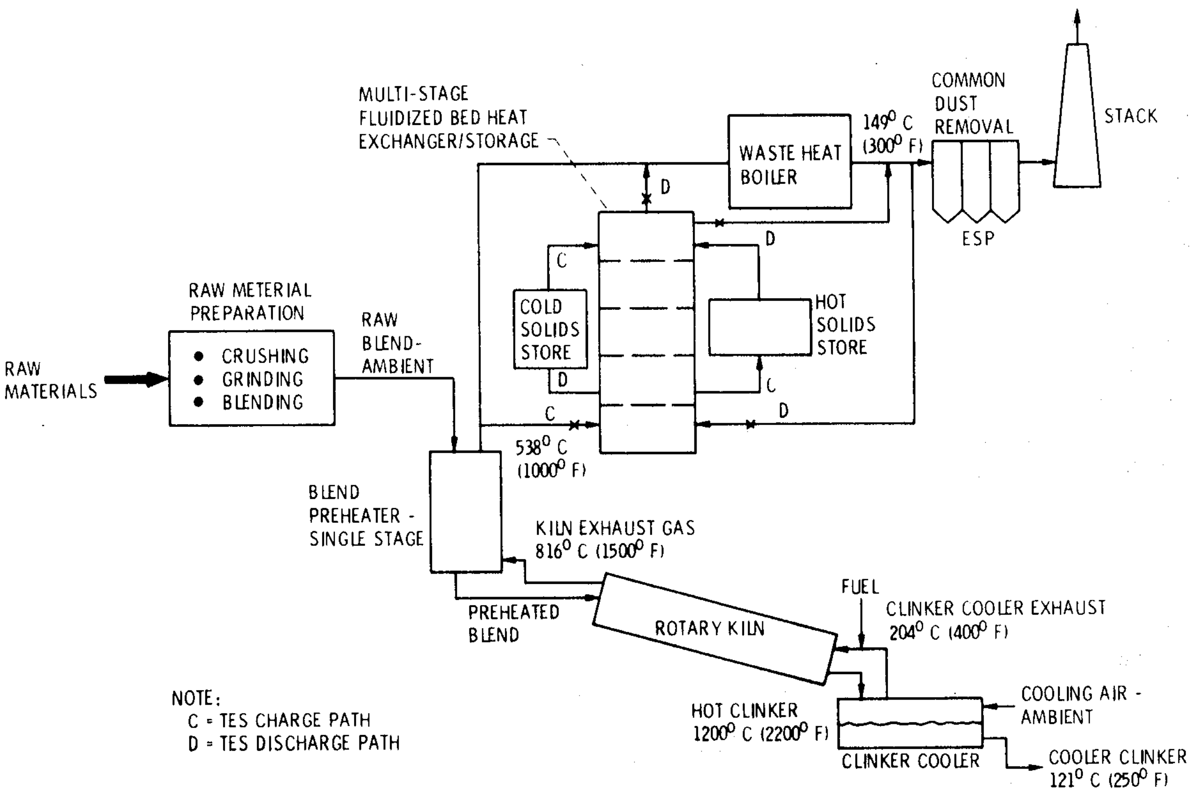


Figure 9. - Fluidized bed TES for cement plant rotary kiln.

ADVANCED MEDIA STUDIES

In many instances thermal performance of a system could be improved or the cost of energy reduced if advanced TES media were available. Activities in this category are conducted to identify candidate media that offer the potential for low cost, etc. The characteristics of the candidate media are studied to determine if cost reductions might be obtained if new methods of extracting or processing the materials are employed. The corrosion characteristics of the media are evaluated to determine what types of materials are suitable for containing the media. A literature search may be conducted to determine if the appropriate properties for TES have been determined and if the reported values agree sufficiently well. If warranted, studies would be performed to determine properties such as specific heat, latent heat of fusion, and thermal conductivity for the purities expected in production quantitites appropriate for TES applications.

There are two efforts that are investigating advanced media; the first is evaluating carbonate salts for high temperature applications and the second is a feasibility study of using metal alloys as TES media.

INSTITUTE OF GAS TECHNOLOGY
(DEN 3-156)

The Institute of Gas Technology has been investigating carbonate salt mixtures as viable candidates for high temperature applications. Under the auspices of ERDA, Contract No. EY-76-C-02-2888, "Molten Salt Thermal Energy Storage Systems", the apparent attractiveness of carbonate salts was ascertained. The investigation was extended under a DOE funded NASA Contract, NAS3-20806, "High Temperature, Molten Salt, Thermal Energy Storage System", to identify carbonate salts which could be used for specific applications, such as, in the superheat region of a water-Rankine cycle and in the 1000-1600°F proposed temperature range of solar power systems. The carbonate salts at the low end of the temperature range (1000°F) were evaluated experimentally during Contract NAS3-20806 and candidate carbonates were identified for the upper end of the temperature range. The present effort, "High Temperature, Molten Salt-Latent Heat, Thermal Energy Storage Development for Solar Applications", DEN 3-156, is a continuation of the previous work to select and test latent heat carbonate media, containment materials, and thermal conductivity enhancement (TCE) materials for high temperature applications (1300°F - 1600°F) such as advanced solar-thermal power generation systems. There are three tasks in the present effort: material compatibility testing, property measurements, and reporting.

The first task includes the selection of six candidate carbonate salts, five containment materials, and two thermal conductivity enhancement materials on the basis of thermal performance, cost, and operational lifetime. Compatibility screening tests of 1000 hours and 3000 hours of the salt/containment/TCE materials will be performed to identify the most promising combinations.

This task also includes an evaluation of the effects of using low-cost technical-grade salts on corrosion of the containment and TCE materials, and stability of the salts themselves.

The second task includes the measurement of properties such as thermal conductivity, heat capacity, heat of fusion, volumetric changes during phase transitions and melt temperature. Much of this data for salts in the 1300 to 1600°F temperature range is either unavailable or the data that is available is inconsistent. The third task includes the technical, schedular, and financial reporting.

UNIVERSITY OF DELAWARE (NSG 3184)

The University of Delaware has a grant "Heat Storage in Alloy Transformations" NSG 3184 to determine the feasibility of using metal alloys as thermal energy storage media. The metal alloys have the advantage of having a relatively high thermal conductivity in the solid state compared to other materials being considered as TES media. The high thermal conductivity results in less resistance to heat transfer to and from the storage media during charge and discharge portions of the energy storage cycle.

The project has four major tasks: (1) the identification of congruently transforming alloys and thermochemical property measurements, (2) the development of a precise and convenient method for measuring volume change during phase transformation and thermal expansion coefficients during heating and cooling, (3) the determination of materials that can be used to contain the metal alloys, and (4) analysis of thermal performance and cost estimation for selected concepts.

The elements selected as candidate media were limited to aluminum, copper, magnesium, silicon, zinc, calcium and phosphorus on the basis of low cost and high latent heat of transformation. Several new eutectic alloys and ternary intermetallic phases have been determined. A new method employing x-ray absorption techniques was developed to determine the coefficients of thermal expansion of both the solid and liquid phases and the volume change during phase transformation from data that are obtained during one continuous experimental test. Candidate materials are being evaluated to determine suitable materials for containment of the metal alloys. Graphite has been used to contain the alloys during the volume change measurements. Silicon carbide has been identified as a promising containment material and surface-coated iron alloys are being considered. Finally, an effort was recently initiated to analytically predict the thermal performance and estimated cost of two concepts. Several concepts are presently being reviewed to determine the most appropriate concepts for analysis.

ENGINEERING EVALUATION OF TES MODULES

LEWIS RESEARCH CENTER

NASA-LeRC obtained two prototype TES modules to experimentally assess the present state-of-the-art of selected concepts. The modules were operated to determine factors such as heat transfer rates to and from storage, heat loss, and long-term operational characteristics. The first module utilizes the latent heat of fusion of sodium-hydroxide to store off-peak generated energy which is then used to provide hot water for domestic use. The unit was built by the Comstock and Wescott Company of Cambridge, Massachusetts and uses primarily sodium-hydroxide with additives to inhibit corrosion of the mild steel containment vessel. This module has been operated to characterize performance and long term tests were initiated.

The second module utilizes the solid-solid phase transition of sodium-sulfate to store energy in a dual-media concept. The relatively inexpensive sodium-sulfate is used to reduce the amount of relatively expensive heat transfer fluid required in the storage module. The module was obtained from the Calmac Manufacturing Corporation of Englewood, New Jersey. The unit has been operated to determine the performance characteristics of one sodium-sulfate pebble configuration. A second pebble configuration will be evaluated to determine the effect of pebble size on characteristics such as heat transfer rates and pressure drop.

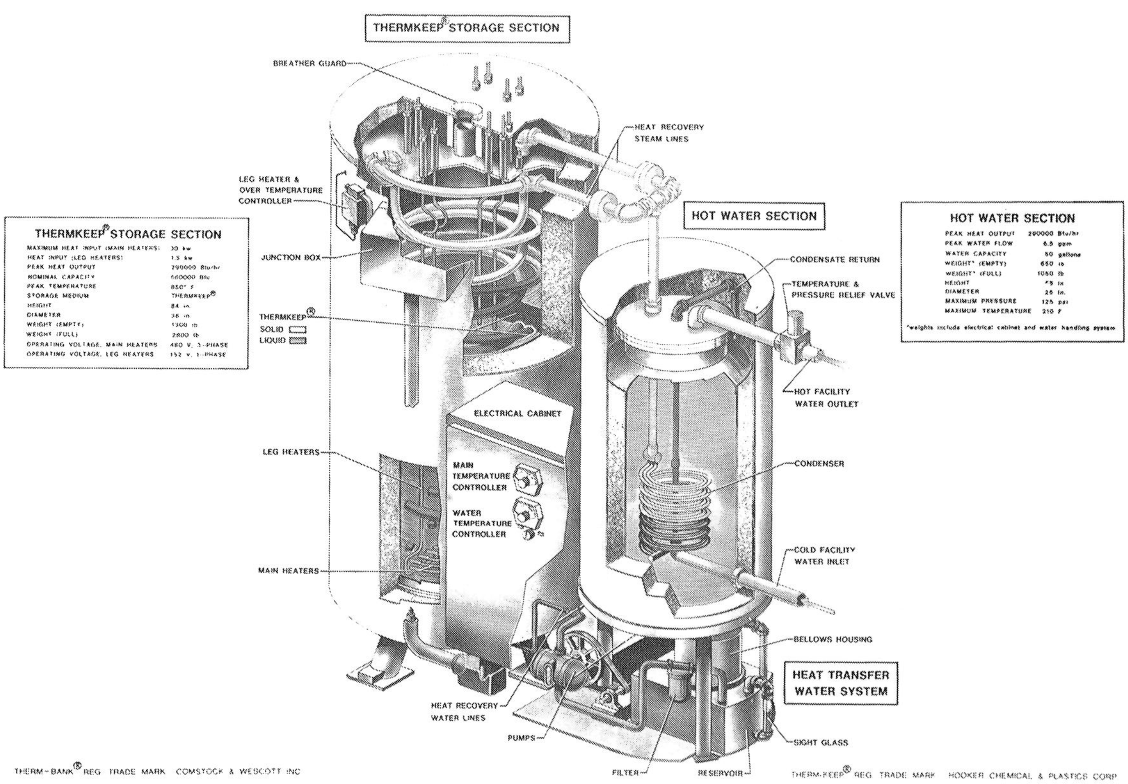


Figure 10. - Therm-bank electric water heater.

ACCOMPLISHMENTS

NEW CONCEPTS

- Completed MRI assessment of fluidized beds for thermal energy storage subsystems. Fluidized beds were found to be marginally competitive for near-term, baseline, industrial applications.

ADVANCED MEDIA

- Initiated high temperature (1300 to 1600°F) carbonate media study with IGT. Selected media/containment material/thermal conductivity enhancement material test matrix. Initiated 1000 hour compatibility tests.

- The University of Delaware completed identification of candidate metal alloys and refined the equipment used to measure volume change of the alloy media. An analytical effort was initiated to predict thermal performance and cost of two concepts which are to be determined.

ENGINEERING EVALUATIONS

- Conducted tests to determine performance characteristics of the Thermbank module (sodium-hydroxide primarily). Initiated life tests of the module. Returned module to Comstock and Wescott for modification when heaters failed early in life testing.

- Performed tests on Calmac dual-media module that utilizes pellets of sodium-sulfate and Therminol 66 as the heat transfer fluid to determine performance of module with almond shaped pellets. Initiated tests using second configuration of sodium-sulfate pellets (broken chips 1/2 inch in diameter).

ISSUES

- None

ACTIVITY SCHEDULE

ACTIVITY

2.1 Fluidized bed microencapsulated PCM laboratory tests

2.2 Na/Mg/Fluoride phase change material investigation

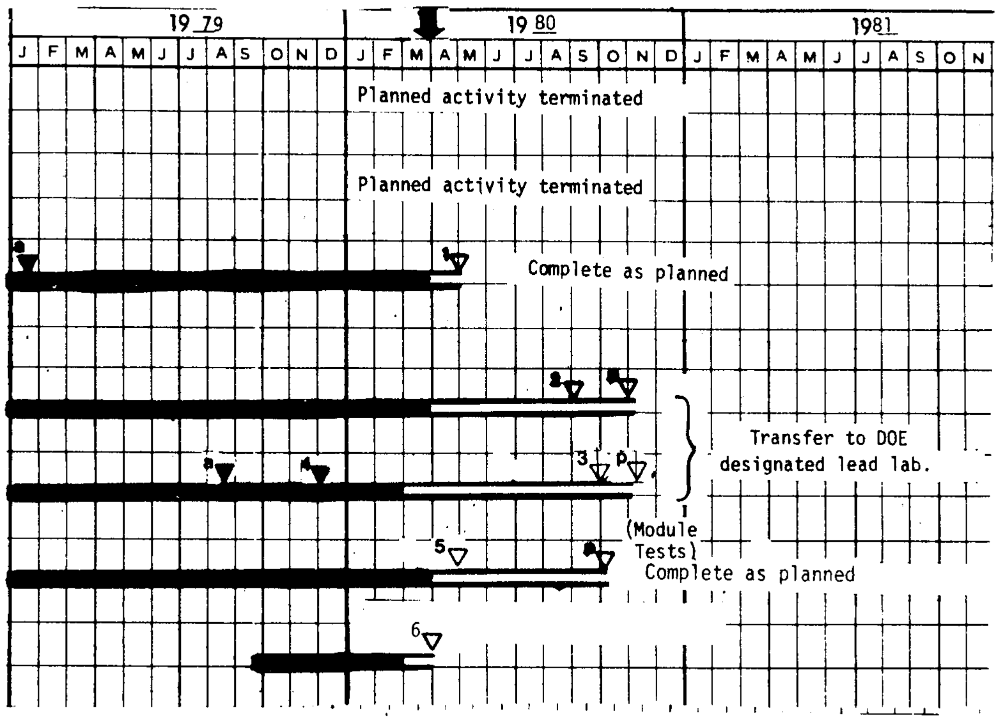
2.3 Assessment of systems using fluidized bed heat exchangers (CP: MRI DEN 3-96

2.4 Thermophysical property measurement of metal alloy media (SS: University of Delaware) NSG 3184

2.5 High temperature molten-salt latent heat TES lab. studies (SS: IGT) DEN3-156

2.6 NASA-LeRC in-house experiments (Calmac and Thermbank module

2.7 Sensible heat storage experiments for CAES (CP: TBD)



1. Complete assessment and establish concept feasibility
2. Define follow-on system design task
3. Complete testing of laboratory modules
4. Review and select materials/concepts
5. Complete Calmac and Thermbank tests
6. Complete activities in support of CAES system

▽	Milestones
▽1	Rescheduled Activity
▼	Completed Activity
S	Establish SEB
r	Release RFP
a	Award Contract
P	Publish Report
SS	Sole Source Procurement
CP	Competitive Procurement
IAA	Interagency Agreement
DHP	DOE Headquarters Procurement
PA	Planning Activity

3.0 INDUSTRIAL STORAGE APPLICATIONS

BACKGROUND

Significant conservation benefits and the substitution of domestic non-critical fuels for critical fuels (oil and natural gas) are possible through the use of thermal energy storage (TES) of industrial process and reject heat for subsequent use. The use of TES can either provide conservation through reject energy recovery and reuse or permit a shift in fuel from oil or natural gas to other non-critical fuels. One of the goals of the Department of Energy's (DOE) Division of Energy Storage Systems is to provide the storage technology capability to provide at least 10% of the industrial process heat or energy requirements of the U.S. industry by the year 2000. The purpose of Industrial Storage Applications is to develop TES systems capable of contributing to the achievement of DOE's goal for the year 2000.

In order to achieve this long range goal it is clear that in the mid-term time frame (CY 85-90) demonstration of conservation of significant amounts of critical fuels is required. The groundwork to do this was started with an Energy Research and Development Administration (ERDA) funded study to determine the economic and technical feasibility of TES in conjunction with waste heat recovery. This study was directed toward identifying industrial processes characterized by fluctuating energy availability and/or demand, a key criterion for TES applicability.

At least twenty (20) industries were identified as areas where thermal energy storage had some potential for application. After the conclusion of this general feasibility study program, ERDA issued a Program Research and Development Announcement (PRDA). This PRDA requested proposals for individual studies of specific industries which were to be selected by each proposer. The overall objective was to identify applications of TES in specific industries through these system studies, and in subsequent work develop and validate potential systems, demonstrate feasibility on a large scale, and then transfer the technology to the total industry to obtain widespread implementation.

As a result of this PRDA (and after the then recent metamorphosis from ERDA to DOE) DOE's Division of Energy Storage Systems awarded five contracts to study five industries with potential significant energy savings through the use of TES systems. These industries were paper and pulp, food processing, steel and iron, cement, and primary aluminum. The aluminum study produced results that were applicable to district heating systems. Follow-on work being conducted for district heating applications is not part of this element.

The results of these other four studies indicated that within those industries thermal energy storage of process and reject heat for subsequent in-plant use appears to be economically and technically feasible with significant near-term conservation benefits. Potential

annual fuel savings with large scale implementation of near-term TES systems for these industries is over 9 x 10^6 bbl of oil. This savings is due to recuperation and storage in the food processing industry, direct fuel substitution in the paper and pulp industry, and reduction in electric utility peak fuel use through in-plant production of electricity from utilization of reject heat in the steel and cement industries.

APPROACH

Figure II summarizes in a schedular form the major activities under the Industrial Storage Applications element. Line 1 shows the continuing System Studies and Supporting Technology activity. This activity includes the PRDA System Studies, Heat Transport Applications, Solar Industrial Applications and New or Advanced Applications. The PRDA System Studies produced significant results that were transferred to the activities of Lines 2, 3 and 4. Significant future results from this Line 1 activity will be transferred to the last line as appropriate.

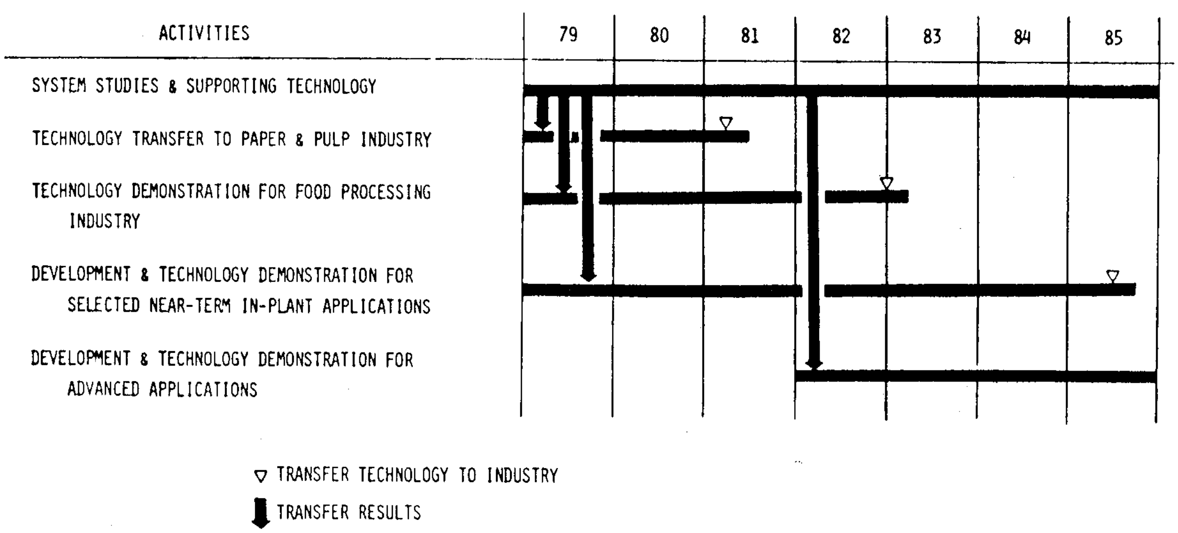


Figure 11. - Industrial thermal storage flow chart.

The technology identified falls into three categories: (1) Existing operational TES system applications for which detailed information has not been made public; (2) promising system applications that involve current technology, require no development, and are ready for immediate technology demonstration to stimulate commercial introduction; and (3) promising system applications that require development prior to a large scale industrial technology demonstration.

TECHNOLOGY TRANSFER

The paper and pulp application (category 1) is depicted in Figure 12. For mills with hog fuel (wood waste) boilers with excess steam generation capacity, TES would allow the substitution of more hog fuel for oil or natural gas. Typically, the base loaded hog fuel boilers with slow response times are augmented by oil or gas boilers to meet rapid steam demands. TES through the use of a steam accumulator, as shown in Figure 3, can provide a load smoothing capability that would directly reduce the use of oil or natural gas.

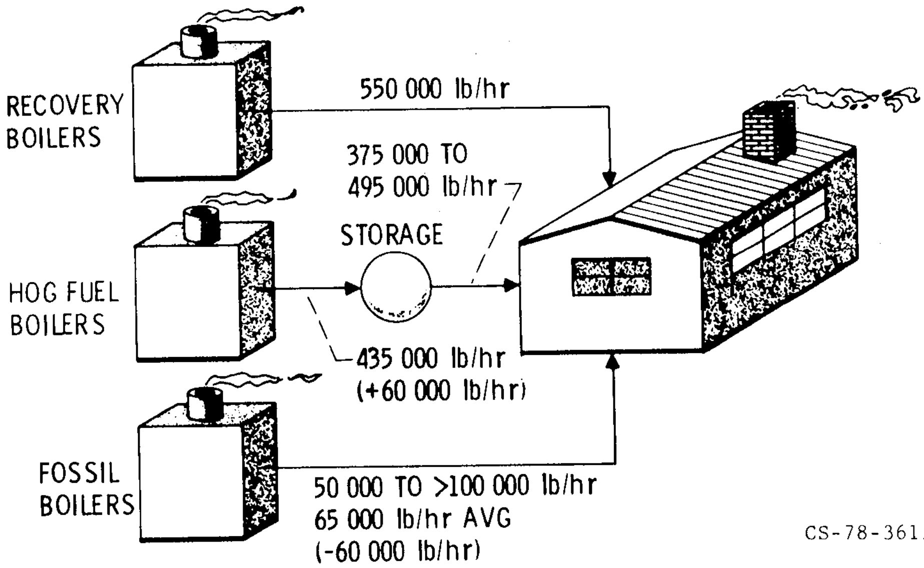


Figure 12. - Energy supply characteristics with thermal energy storage.

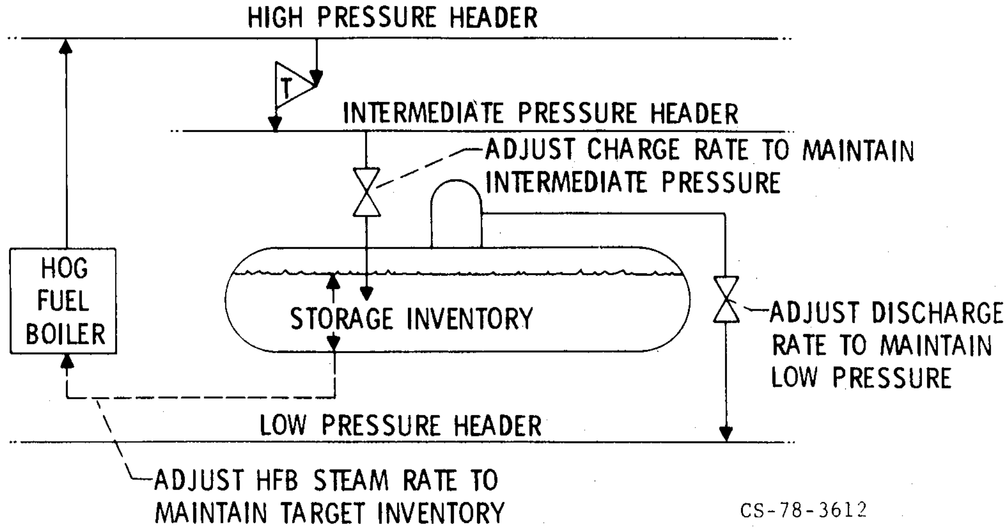


Figure 13. - Variable pressure accumulator TES concept.

HOWARD EDDE
(DEN 3-190)

Mills, both in the U.S. and the Scandinavian countries, have been identified with such TES systems in place. However, information on these systems has not been made publicly available. A contract was awarded for a program to obtain, analyze and disseminate this information to the U.S. paper and pulp industry. The contract was awarded to Howard Edde, Inc. of Bellevue, Washington. The contract consists of three major tasks: (1) Industry Survey, (2) Benefits Analysis, (3) Information Dissemination.

During Task I, the contractor will conduct an extensive survey of both U.S. and Scandanavian pulp and paper mills. He will determine which of the surveyed mills use thermal energy storage. He will then reduce the sample obtained from the extensive survey to a group of mills which in his judgement will be representative of the industry. This representative sample of mills will be surveyed in greater detail to determine the detailed energy flow patterns, both thermal and electrical, related to the mill production processes. If possible, in the case of mills retro-fitted with TES, comparisons of energy usage will be made for the mill processes, both before and after the installation of a TES system.

In Task 2, Benefits Analysis, the data from the representative mills of Task I will be thoroughly analyzed. The broad areas of analysis will include: (a) energy conservation assessment, (b) economic benefits analysis, and (c) environmental impact assessment.

In the final task, the contractor will publicize the benefits of TES obtained in Task 2 to managers and technical personnel in the U.S. pulp and paper industry. This will be done by a number of methods. Presentations will be given at both management and technical meetings of the pulp and paper industry. Brochures to prompt early installation of TES in the industry will be produced and distributed to plant managers and other decision-makers. Technical reports with in-depth data will be provided to engineering personnel. In addition, a display will be designed and fabricated and shown at key pulp and paper industry meetings.

H. J. HEINZ

The food processing application (category 2) is shown in Figure 14. Under DOE sponsorship, the Westinghouse Corporation, with the cooperation of the H. J. Heinz Company, performed an assessment study to investigate the application of Thermal Energy Storage/Waste Heat Recovery (TES/WHR) in the food processing industry. The food processing industry was selected as a candidate industry because it ranked sixth among the nation's industrial users in terms of total energy consumption. Within this industry, the canning segments account for a significant portion of the industry total. The demand for energy by the canning industry is induced by a variety of food processes and process-related operations, such as, cooking, sterilization, and clean-up operations. Oil and natural gas currently supply about 90% of the canning industry's energy needs. The Westinghouse/Heinz study effort identified waste heat sources and applications in typical canning facilities and evaluated TES/WHR systems that would couple the waste heat sources and applications.

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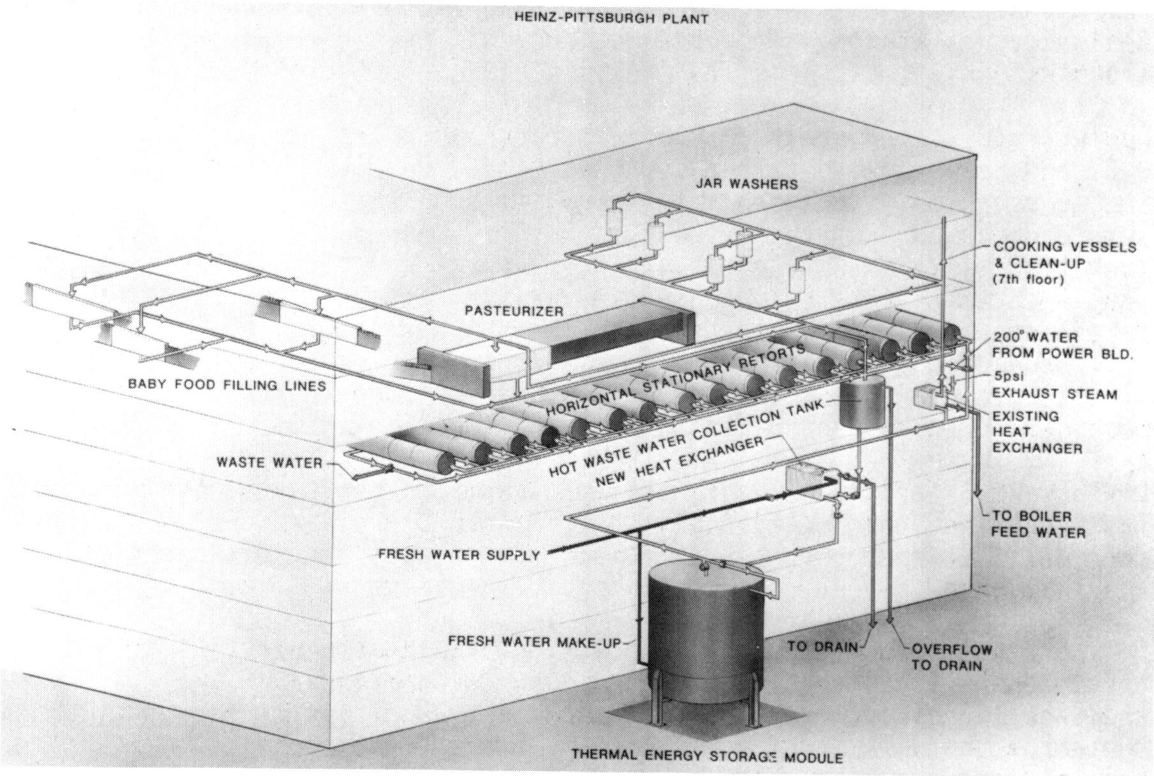

Figure 14. - Thermal energy storage / waste heat recovery system in a food processing plant.

A candidate TES/WHR system application which was typical for the canning industry was identified and evaluated. From the favorable technical and economic results obtained and the potential of early commercialization which would lead to conservation benefits, a technology demonstration was proposed. This system would recover and store waste heat from pasteurizers, sterilizers and can and bottle washers which are used in the baby food and canned soup processing operations in the Meat Products Building at the Heinz Pittsburg Factory. These waste water streams are currently sent directly to the factory drain system as they emerge from the processes. The proposed system would recover heat energy via heat exchangers (to prevent product contamination) to heat incoming fresh water. The heated fresh water would be used immediately for process operations with the excess being stored in the TES module for clean-up operations. The clean-up water requires significant energy input. Heinz estimates that the factory requires 200,000 gallons of heated (150-185^{o}F) water per day which is equivalent to 3-4% of the plant's total energy consumption. Major clean-up is normally performed during the third shift when processing operations are suspended. The use of TES is necessary to match the clean-up requirements with the waste heat supply.

This particular system can be retrofitted in the Heinz factory at a reasonable cost, is of an appropriate size to serve as an effective demonstration of the technology, and is representative of typical applications within the industry. It is estimated that the system will recover 3 x 10^{10} BTU/YR (5000 bbl oil/yr equivalent) and provide an ROI in the range of 35-40%.

The proposed technology program at Heinz Pittsburgh is composed of the following tasks:

1. System Definition Review and Demonstration Plan Preparation:

   Review and update the system study performed under DOE contract EC77-C-01-5002. Develop analytical models and perform analyses required to define an optimum system. Prepare a detailed plan for the TES/WHR technology demonstration which shall define objectives, expected benefits and schedular milestones and provide specifications, instrument requirements, and procedures for all facets of the installation, performance demonstration and evaluation.

2. Technology Demonstration System Design:

   Prepare a detailed engineering design of the TES/WHR technology demonstration system in accordance with the demonstration plan.

3. System Fabrication, Installation and Checkout:

   Procure components and fabricate, install, instrument, and perform functional checkout of the system.

4. Performance Demonstration and Evaluation:

   Proceed with the performance demonstration of the system in accordance with the approved demonstration plan. Perform system analyses and evaluations throughout the demonstration period and determine fossil fuel and net energy cost savings.

5. Technology Transfer:

   Perform a benefit analyses of the system as applied to the food industry and disseminate the information to the industry. Prepare a commercialization plan which provides for the implementation of the TES/WHR systems in the food processing industry at an early date to achieve early and widespread energy savings.

DEVELOPMENT AND DEMONSTRATION

The steel and iron application (category 3) is summarized in Figure 15. Hot gas in the primary fume evacuation system of electric arc steel remelting furnaces is the reject heat energy source. The fume stream would charge a solid sensible heat storage packed bed. Discharge of the TES system through a heat exchanger would generate steam to drive a turbogenerator. TES is used to permit electric power to be generated during peak demand times instead of continuously. The economic benefits to be derived from the use of TES for peak power generation is a direct function of either a demand charge, time of day pricing, or a combination of both.

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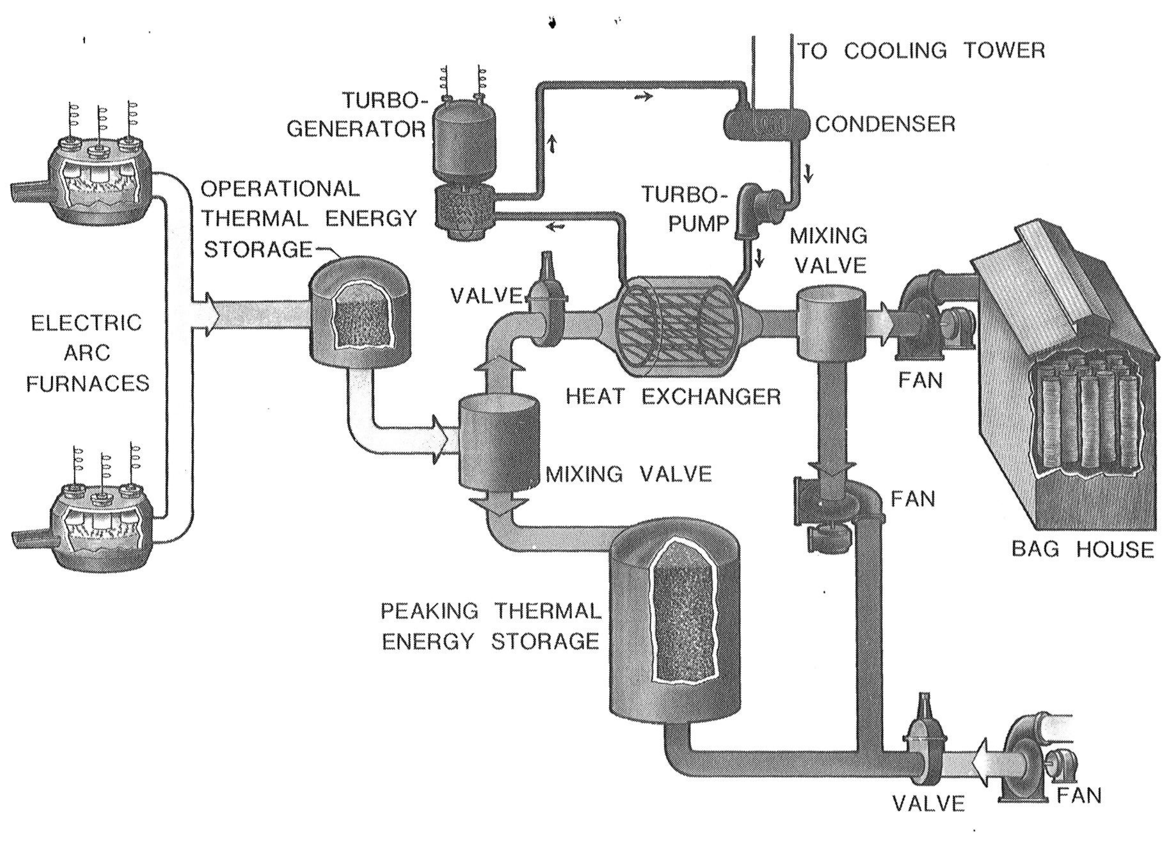

Figure 15. - Steel arc furnace energy recovery & storage system.

Although the TES concept of this study yielded favorable predictions of critical fuel displacement and investment returns, the approach is not ready to be applied directly to a full scale demonstration without an interim concept development period. Therefore, any further work will have to be as a result of competition with other applications in a similar state of readiness.

The cement application (category 3) is shown in Figures 16 and 17. Hot gas from a long, dry-process cement kiln would be used in a waste heat boiler to produce steam for driving a turbogenerator to produce electricity for in-process use. Approximately 80-90% of the kiln exit gas would go directly through the waste heat boiler with the rest being used to charge a solid sensible heat storage packed bed. When the kiln is down for maintenance the packed bed would be discharged through the waste heat boiler thereby eliminating a power demand charge which could be significant.

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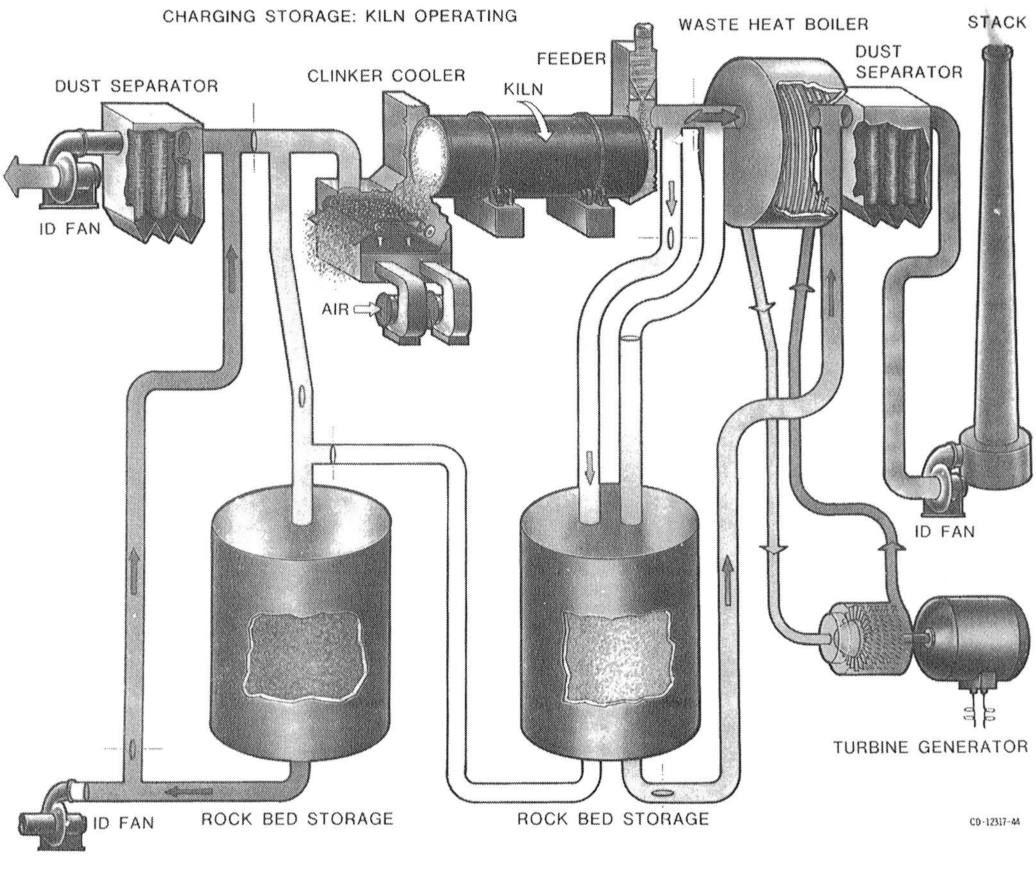


Figure 16. - Cement plant energy recovery & storage system.

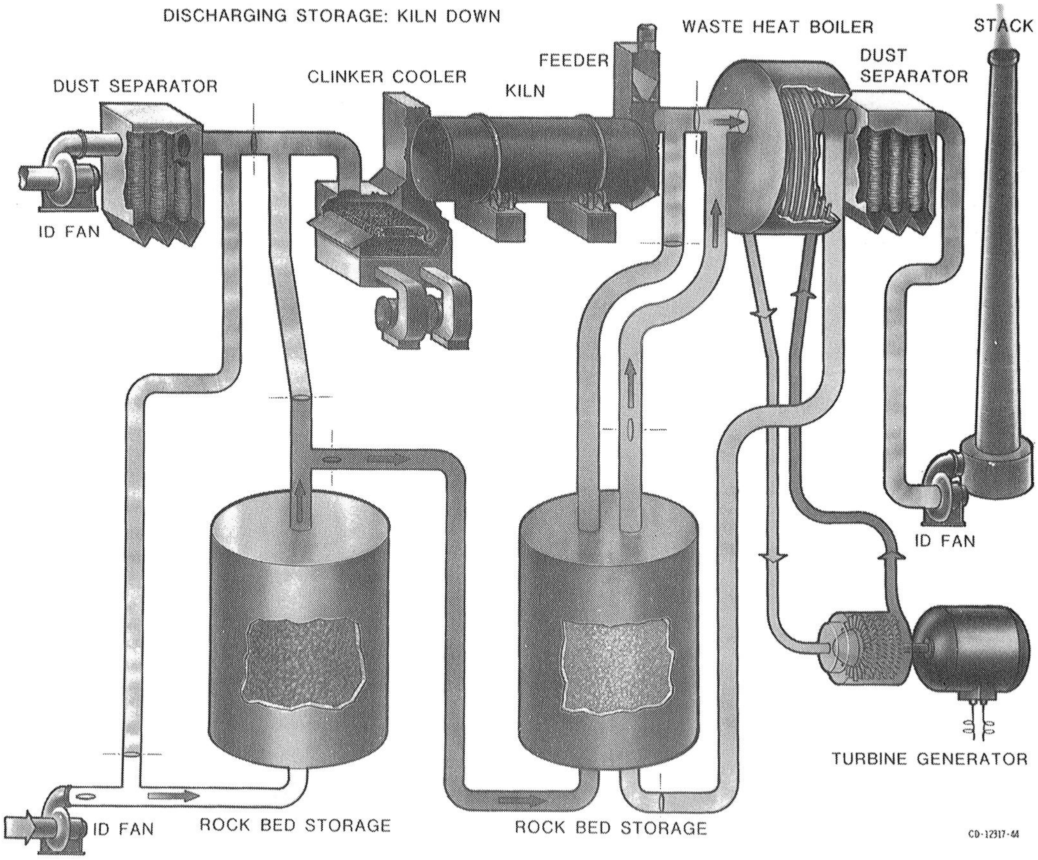


Figure 17. - Cement plant energy recovery & storage system.

The results of the cement study are similar to those of the steel study. Favorable predictions of critical fuel savings and investment returns resulted, but an interim concept development period would be required.

A procurement activity is in progress for the development and technology demonstration of thermal energy storage systems for industrial process and reject heat applications. This will be a competitive procurement with multiple awards planned. Because of the contracts involving TES in the paper and pulp and food processing industries, these industries are being excluded from this procurement. The emphasis of this procurement is to more fully evaluate U.S. industry for other applications of in-plant use of stored thermal energy using cost-effective near-term technology. In-plant use is being specified to preclude proposals for district heating applications which are being adequately covered by the follow-on effort to the aluminum study.

The objective of this procurement is to develop, if needed, and demonstrate TES systems that offer the potential of saving significant quantities of energy or critical fuels in the near-term on a cost-effective basis. Specific goals are to: contribute to the DOE goal of providing 10% of the U.S. industry's process heat or energy requirements by the year 2000 through thermal energy storage; be cost-effective by providing a return-on-investment that will significantly attract broad scale implementation; be acceptable by the industry as being operationally safe and reliable; and be environmentally acceptable. Cost-sharing will be an important factor in contract awards for this procurement.

This effort will be conducted in two phases, a Design, Anlaysis and Development Phase, and a Technology Demonstration Phase.

The goal of Phase 1 is to provide information that is extensive and reliable enough to permit the proper determination to be made for proceeding with the Technology Demonstration of Phase 2.

Phase 1 will cover the conceptual design and analysis of the thermal energy storage system and a benefit analysis for the specific industry selected. If component and subsystem development is required for the TES system proposed, it will be performed. Concluding this phase will be the preparation of a Technology Development Plan, a Preliminary System Design and a major review.

At this review the Government and the Industrial Participant will review all technical, economic, and environmental aspects of the system design approach. After agreement is reached that contract continuation is justified, Phase 2 will be initiated.

The goals of Phase 2 are to: establish the basis for the technical and economic feasibility of the concept on a plant size scale; confirm system reliability and verify performance characteristics for potential users; provide experience for the integrated operation of the system in a real life plant setting; insure availability of required technology; and accelerate acceptance by private industry.

Phase 2 will consist of the large-scale Technology Demonstration of the TES system in an in-plant application. This will include the detail final design, fabrication, installation, checkout, operation and evaluation of the TES system. Phase 2 will conclude with a major effort to transfer technology to the remainder of the industry with the expectation that commercialization and rapid implementation of TES systems within the industry will follow.

ACCOMPLISHMENTS

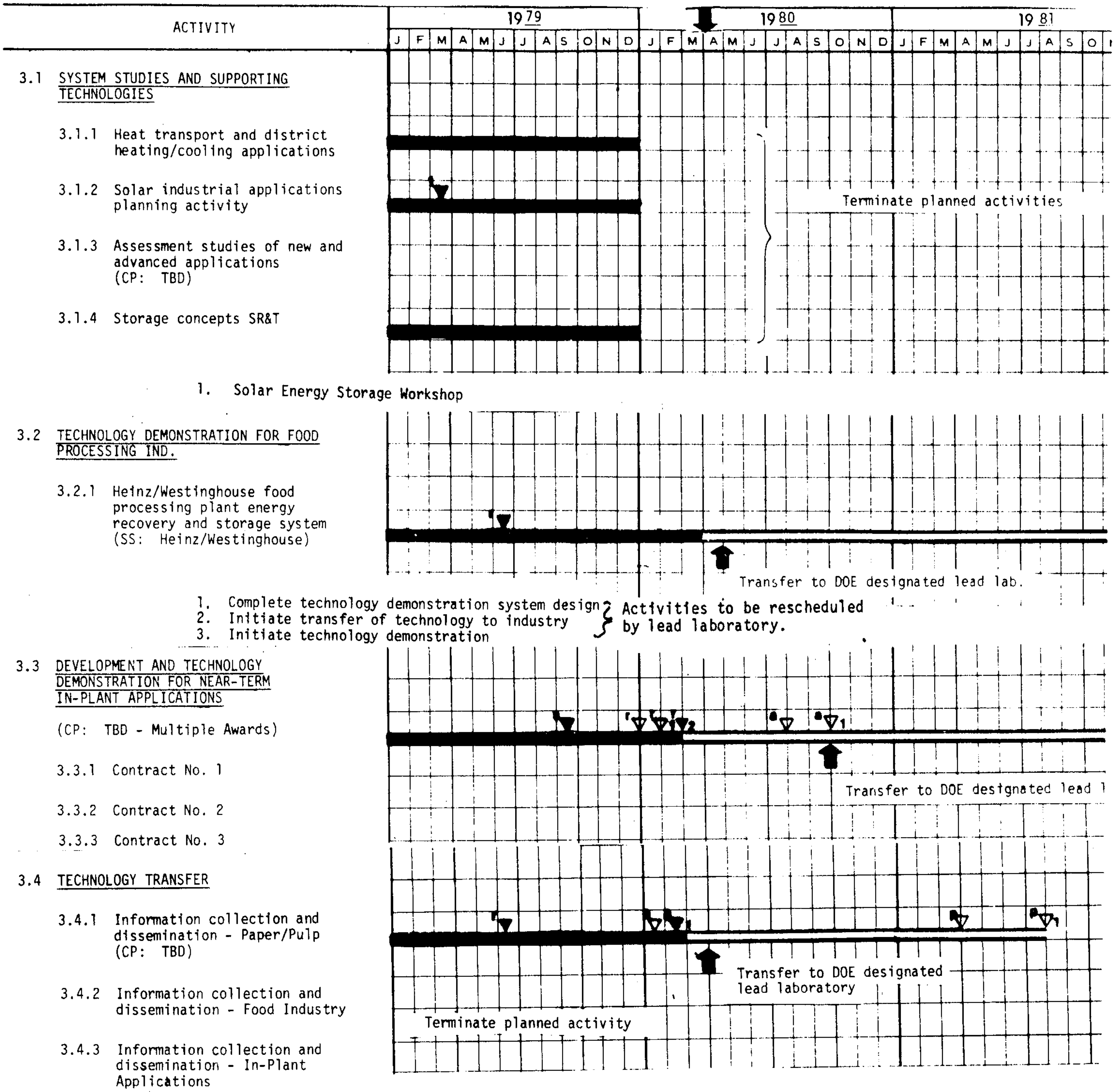
- o Awarded Contract DEN 3-190; "Collection and Dissemination of Thermal Energy Storage System Information for the Paper and Pulp Industry", Howard Edde, Inc.
- o Released RFP 3-152012Q, "Thermal Energy Storage Technology Demonstration for Food Processing Industry".
- o Released RFP 3-161609Q, "Development and Technology Demonstration of Thermal Energy Storage Systems for Industrial Process and Reject Heat Applications".

ISSUES

- Ownership of Technology Demonstration Equipment - The government cannot pay for non-severable equipment. Therefore, a distinction must be made for severable and non-severable components of any technology demonstration system.

- Disposition of Severable Equipment - The government cannot give title of government purchased severable equipment to the Industrial Participant "up-front". Therefore, the Industrial Participant may be hesitant about providing a technology demonstration site.

- Cost Sharing - If the Industrial Participant's cost share covers the cost of the technology demonstration system, there is no ownership problem. However, the equipment cost will probably exceed the anticipated cost share. Also, cost sharing will probably be offered in many different ways, e.g., labor costs, energy costs, recoupment based on actual energy savings, etc.



▽ Milestone
▽1 Rescheduled Activity
▼ Completed Activity
s Establish SEB
r Release RFP
a Award Contract
P Publish Report
SS Sole Source Procurement
CP Competitive Procurement
IAA Interagency Agreement
DHP DOE Headquarters Procurement
PA Planning Activity

4.0 SOLAR THERMAL POWER STORAGE APPLICATIONS

BACKGROUND

Major considerations impacting the development of solar thermal power systems for commercial applications are the need to provide continuous operation during periods of variable insolation, to extend operating periods into nonsolar hours, to buffer potentially harmful transients induced by abrupt insolation changes, and to assure the availability of productive capacity in emergency periods. Two options exist for meeting these requirements: conventional backup systems, (including utility grids, fossil-fueled systems, batteries, pumped hydro, etc.) and thermal energy storage. Backup systems provide a viable near-term solution; however, as conventional fuel supply becomes critical due to cost or availability, thermal storage will assume an increasingly important role.

To facilitiate the accelerated development of thermal energy storage technologies matched to solar thermal system requirements and scheduled milestones, the DOE Divisions of Central Solar Technology and Energy Storage Systems requested the preparation of a comprehensive program plan for implementation in FY 1980-1985. Inputs to the plan were provided by a task force consisting of representatives of Sandia Laboratories Livermore (SLL), Sandia Laboratories Albuquerque (SLA), NASA Lewis Research Center (LeRC), Jet Propulsion Laboratory (JPL), Aerospace Corporation, the Solar Energy Research Institute (SERI) and PRC Energy Analysis Company. Lead management for drafting the program plan was assigned to LeRC.

In April, 1979, LeRC, SLL, and SERI reached a tentative agreement (subsequently approved by DOE) whereby SLL would implement major developments within the program associated with focused solar thermal applications. SERI's prime responsibility would be applied research of thermal storage technologies which provide a base for technology development in high risk areas. LeRC agreed to provide overall technical and resource program management, including the necessary coordination with other aspects of the DOE thermal storage program, planning and preparation associated with program reviews, workshops, multi-year plans and annual operating plans for both the SLL and SERI activities. In addition, LeRC would continue laboratory-scale development of selected storage technologies which appeared to be potential candidates for large scale development within the SLL program. It is progress made in these program planning and management activities, and related concept developments, that is the subject of this section of the report.

APPROACH

The activities within this project element can be categorized as follows: (1) Program Management and (2) TES Concepts Development.

Program Management: A program was established within the term of this report to develop thermal energy storage technologies for a wide range of both large and small solar thermal power system applications. (An illustration of thermal storage integrated into a large solar thermal electric power system is presented in Figure 18.)

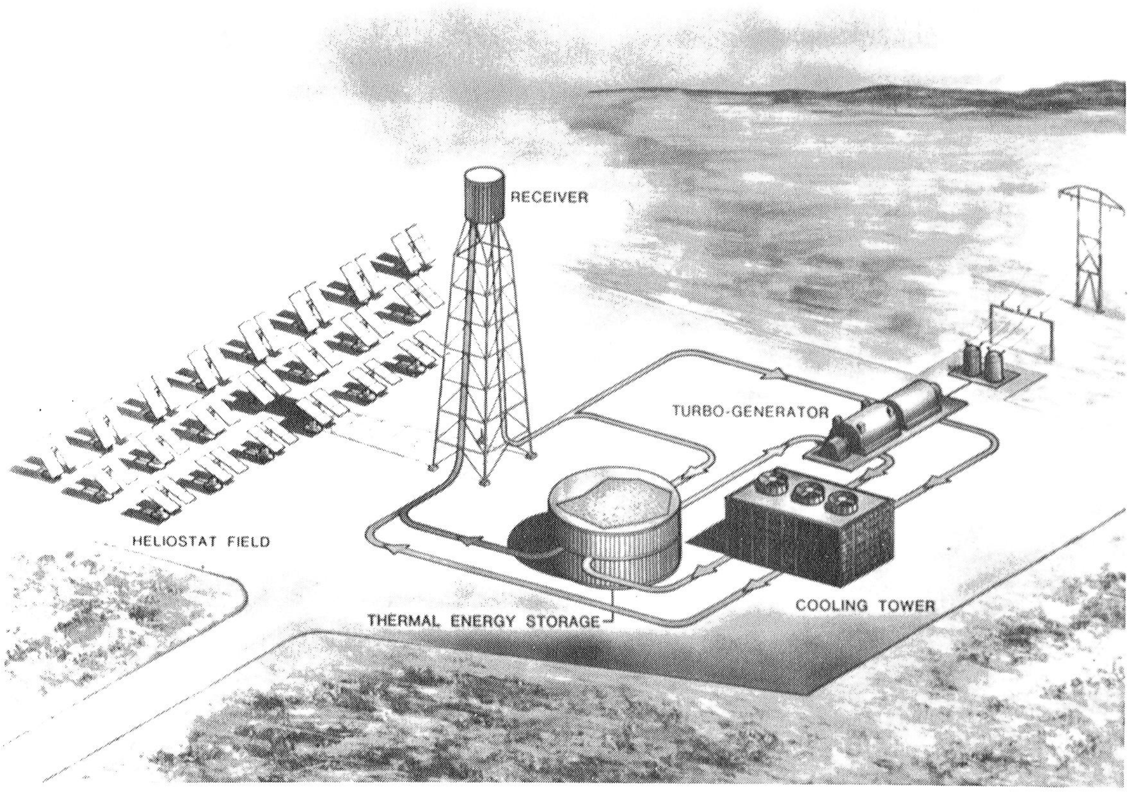


Figure 18. - Solar thermal power systems.

The objectives of the program are to:

1. Develop 2nd generation storage subsystems offering substantial cost/performance improvements.

2. Establish a technology base for 3rd generation storage concepts.

3. Provide engineering support for 1st generation storage technologies.

SLL was designated by DOE as lead laboratory for solar thermal applications. As such, LeRC provided technical and financial direction to SLL targeted at meeting the first and third program objectives. Priorities were established which reflect both the current direction of the Thermal Power Systems (TPS) Branch, CST, and the projected FY 80 funding constraints. This resulted in an initial emphasis on repowering/industrial retrofit, total energy, and small community system applications. Cost and performance goals were established for each major development aimed at large electric power systems. Procurement packages and proposed in-house activities were reviewed for consistency in meeting program objectives. Periodic reporting procedures were established, and draft annual operating plans reviewed prior to their submittal to DOE for approval. A number of program overviews were made at both "customer" division program reviews and technical society conferences, describing the evolution of the program and the FY 80 implementation thereof.

DOE delegated responsibility for meeting the second program objective to SERI. In the capacity of program manager, LeRC assisted SERI in establishing a project team to perform systems analyses and technology assessments, to conduct research and small-scale development of advanced storage and transport concepts, and to coordinate storage activities with lower temperature solar thermal application sectors such as agriculture and process heat and solar heating and cooling. Reporting procedures and operating plans were established, and SERI was funded to conduct an annual workshop, attended by cognizant managers of both TPS and STOR, to critique the overall program plan and FY 80 implementation structure, and to provide direction and emphasis for FY 81 activities.

TES Concepts Development: A major problem associated with utilization of the heat of fusion of molten salts is accumulation of salt deposits on discharge tube surfaces. This accumulation imposes a large heat exchanger surface area requirement, which can be the major cost item of the system.

To minimize a potentially large capital investment in required heat exchangers, Honeywell, Inc. and the Grumman Aerospace Corporation are developing laboratory-scale concepts to enhance energy removal from a TES module by actively inhibiting or removing the formation of salt depositions on discharge tube surfaces, (contract nos. DEN 3-38 and DEN 3-39, respectively).

HONEYWELL
(DEN 3-38)

Honeywell has completed tests of two active heat exchange experiments and has submitted a draft of the final report for review. The concepts, called a Coated Tube Flowby experiment and a Direct Contact Reflux Boiler experiment, were identified in the conceptual design phase of the study as having significant cost and performance improvement potential relative to a tube-intensive latent heat storage system. The Coated Tube Flowby experiment is based on coating discharge tube surfaces with various anti-stick materials such as nickel, chrome, Teflon or Ryton. The Direct Contact Reflux Boiler experiment is an extension of a current commercial process, used in the manufacture of sodium nitrate, whereby water is injected directly into the salt melt, vaporized as the salt freezes, and then condensed on discharge tube surfaces. A variation of the experimental Reflux Boiler module, with continuous salt flow and hydraulic heat recovery, is presented schematically in Figure 19.

The results of both concepts were disappointing. Although qualitative 'dip' tests seemed to indicate that several coatings might alleviate the problem of salt freezing on discharge tube surfaces, tests using an electroless nickel coating in the Coated Tube Flowby experiment confirmed that salt adhesion still had a deleterious effect on heat transfer - to an extent which did not warrant further consideration. Other coatings such as chrome or Teflon were not tested in the Coated Tube Flowby experiment because of schedular and financial constraints.

The Reflux Boiler experienced severe salt degradation. The storage medium, (99-percent $NaNO_3$, 1-percent NaOH by weight) when in contact with water, underwent hydrolysis forming sodium hydroxide and nitric acid. This was compounded by an irreversible chemical reaction of nitric acid with the container walls, forming iron oxides in aqueous solution. As a result, only half the design steam pressure could be achieved in the Reflux Boiler.

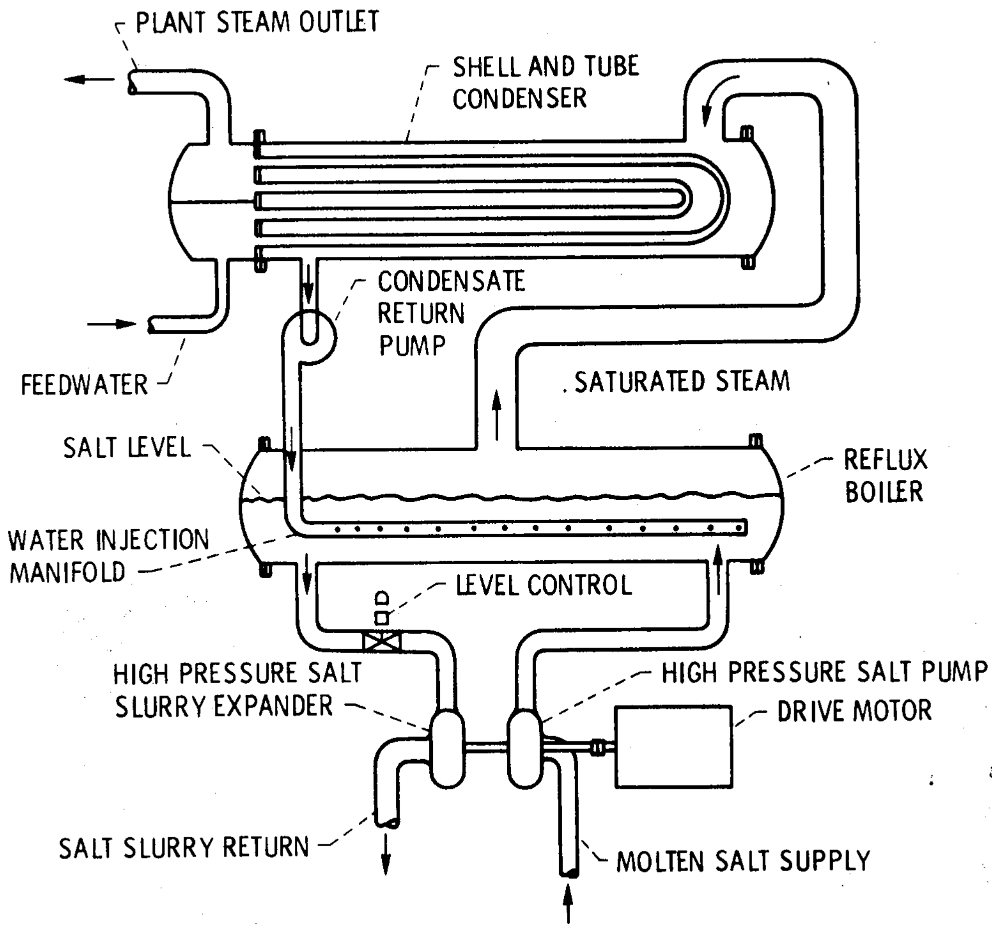


Figure 19. - Continuous salt flow reflux boiler with hydraulic head recovery.

GRUMMAN AEROSPACE
(DEN 3-39)

Grumman is currently in the process of testing the first of two laboratory-scale active heat exchange test modules, called the Direct Contact Heat Exchanger. This module is designed to interface with an intermediate heat transport loop which uses a liquid metal eutectic as the fluid. Separate streams of salt and liquid metal are mixed together in a heat exchange column, where, upon discharge, both latent and sensible heat are transferred to the cooler liquid metal by a countercurrent flow of molten salt droplets injected at the bottom of the column. As the salt solidifies, it rises to the top of the column, where it is directed over the edge to the bottom of a surrounding tank. A schematic of Grumman's Direct Contact Heat Exchanger, and a photograph of the experimental installation are presented as Figures 20 and 21, respectively.

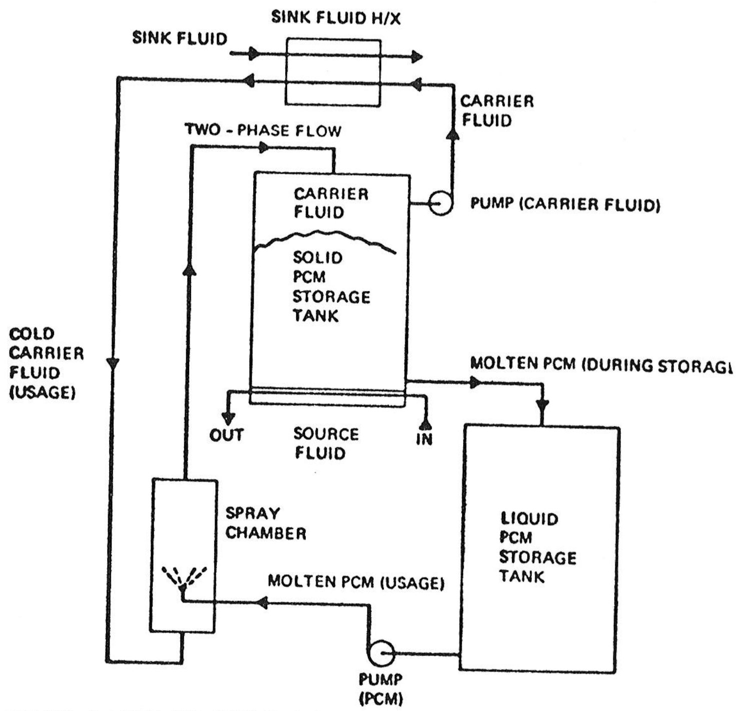


Figure 20 DIRECT CONTACT HEAT EXCHANGER SYSTEM SCHEMATIC

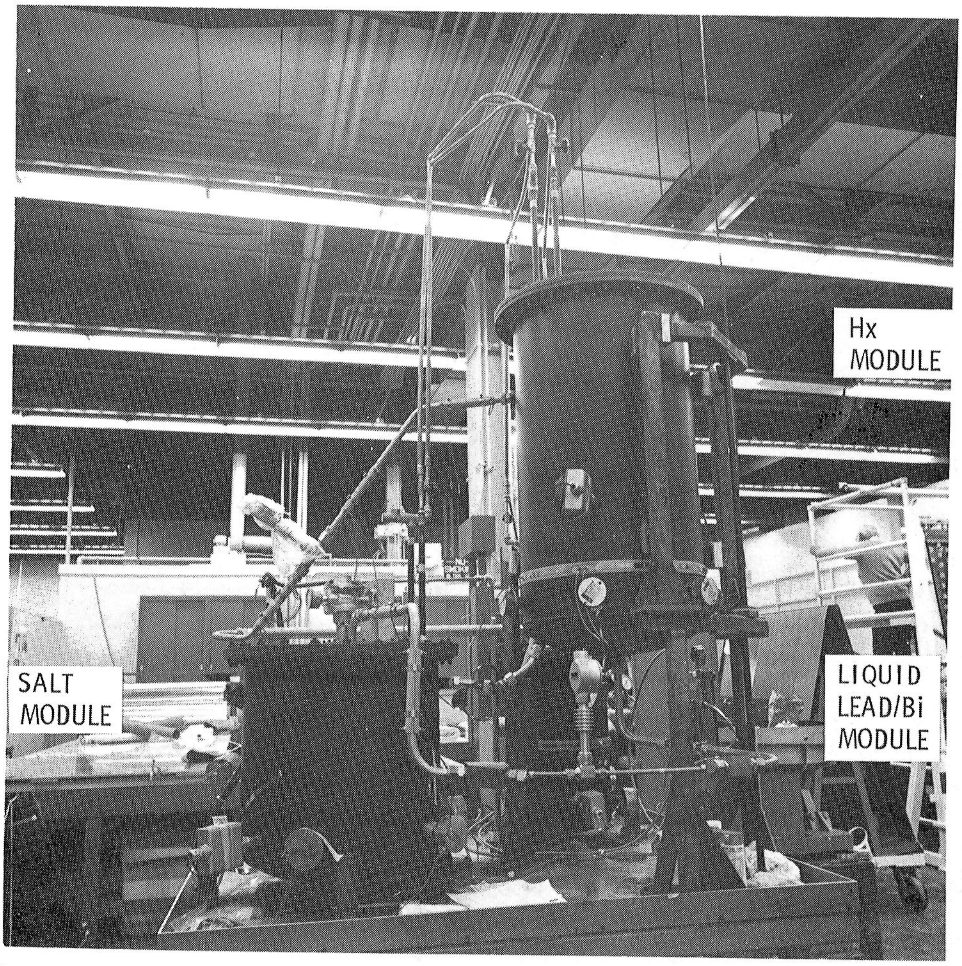


Figure 21. - Direct contact heat exchanger installation.

The second Grumman test module, called a Rotating Drum Scraper, has been fabricated. By design, this unit will mate with the existing hardware of the Direct Contact Heat Exchanger experiment, replacing only the central heat exchange column. It uses the same salt storage medium and liquid metal heat transfer fluid. During the discharge cycle, molten salt flows through slit nozzles onto the circumference of a rotating drum. At the same time, liquid metal flows through an annular passage within the drum, cooling the outer surface and freezing the molten salt. The solidified layer of salt is then scraped off with a fixed scraper blade after the drum has made a particial (270 degree) rotation, falling into a storage bin where it remains until the next charging cycle.

COMSTOCK AND WESCOTT
(DEN 3-138)

First generation phase change storage systems are typified by using passive (no moving parts), tube intensive heat exchangers. The present contract with Comstock and Wescott is a continuation of a prior program which included the design, construction, and testing of an experimental one-tenth scale-model of a phase change thermal energy storage (TES) system suitable for use in electricity generating systems such as the Sandia Solar Total Energy Test Facility (SSTETF) at Albuquerque, New Mexico. This was used to generate data with which to verify a previously developed computer model of the TES unit. The TES unit employs a single passive internal heat exchanger which is used both for charging and discharging heat by means of a non-phase change heat transfer fluid such as Therminol-66. The TES unit and test bed are described in ref. 1.

The nominal composition of the TES medium (Thermkeep) is:

Anhydrous NaOH, commercial grade	91.8% (wt)
$NaNO_3$	8.0
MnO_2	0.2

The commercial grade of NaOH typically contains 1-2% of NaCl and 1-2% of Na_2CO_3.

The present program which is nearing completion includes the following tasks:

1. The experimental module developed under the prior contract was examined to determine whether or not deterioration has occurred during the testing, such as mechanical damage to the heat exchanger, or chemical changes in the TES medium. Figure (22) shows the heat exchanger in the tank, exposed for examination. No significant changes were observed and it was concluded that no repair was required before proceeding with Task 2.

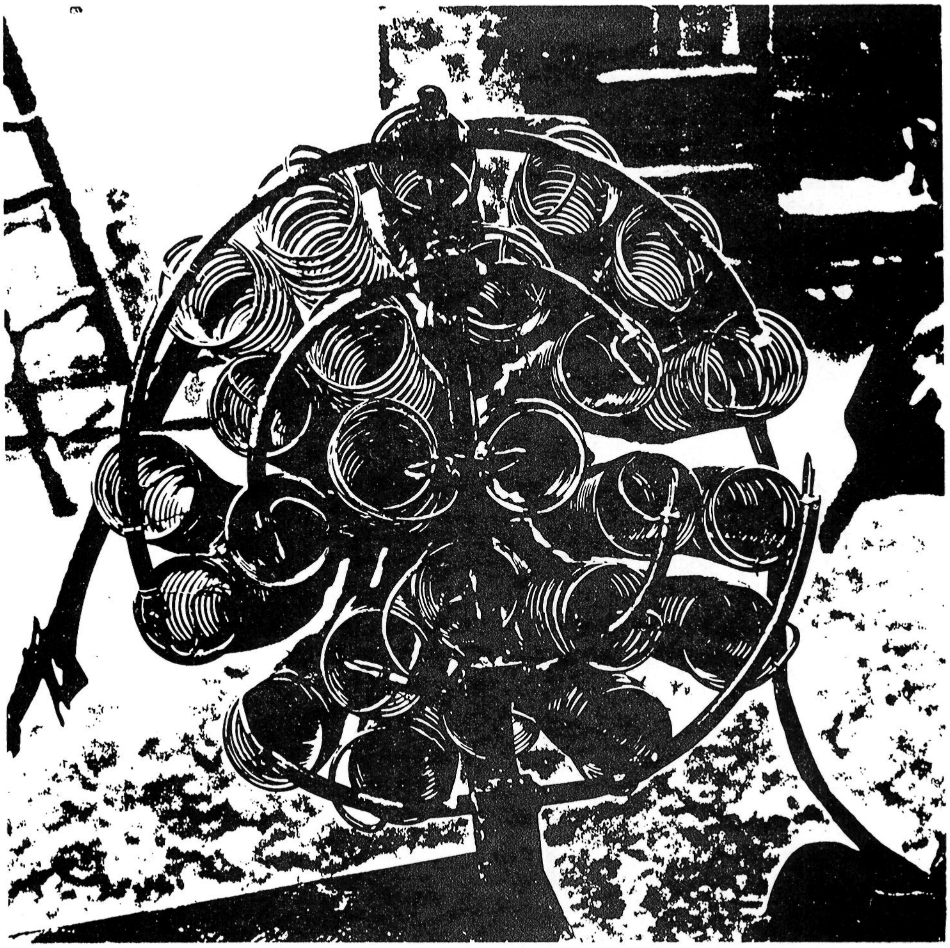


Figure 22. - Passive heat exchanger.

2. The TES system was restored to operating conditions, installation of a different heat transfer fluid approved by the NASA Program Manager, and the running of a series of thermal charging and discharging cycles to obtain additional experimental data for correlation with the computer model for further validation. From among the candidate heat transfer fluids, NASA approved Caloria HT-43, a product of Exxon Corporation. Tests included charging and discharging at constant rates, consecutive cycles at constant charge and discharge rates, and cycles simulating a solar daily cycle. This actual performance compared favorably with performance predicted by the computer model.

3. The computer model was extended to include a second heat exchanger in the TES unit, so that the unit can be charged by means of a non-phase change fluid (e.g., from solar collectors) flowing in one heat exchanger, and discharging by a phase change fluid flowing in the other (e.g., the power fluid of a Rankine cycle engine). See Figures (23), and (24) for comparison.

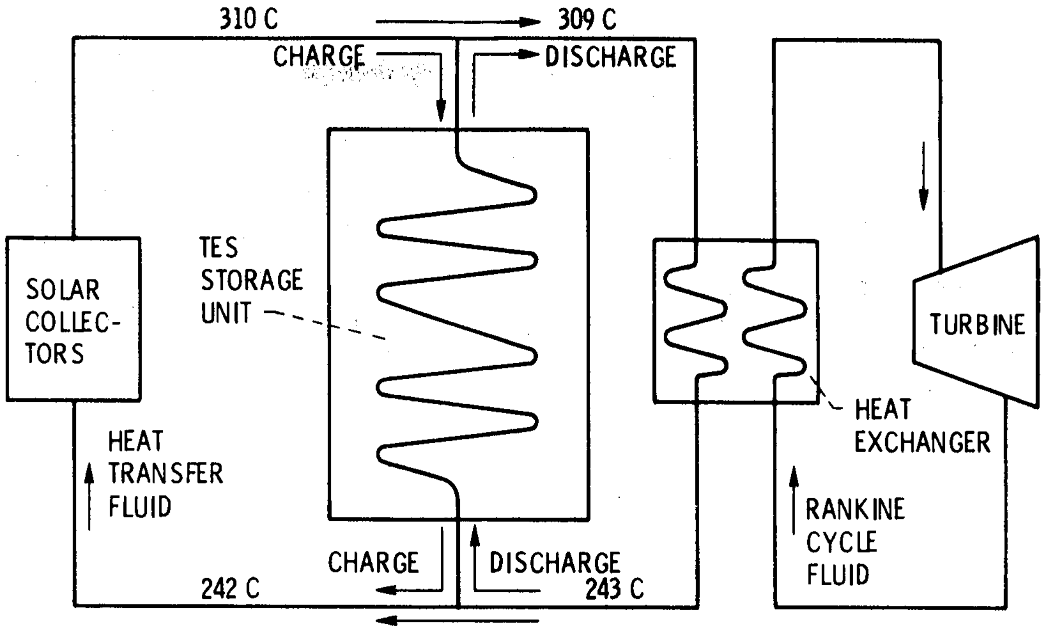


Figure 23. - Schematic of solar powered electricity generating station.

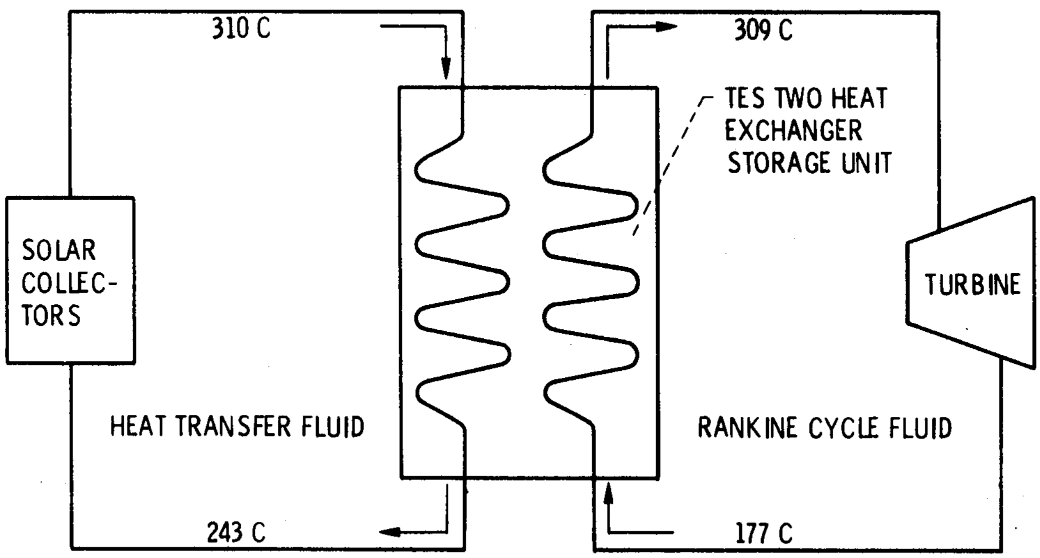


Figure 24. - Advanced dual heat exchanger system.

One potential advantage of the advanced configuration is the elimination of the external heat exchanger. A second and more important advantage is the potential improvement in performance of the TES unit resulting from the fact that during the discharging the temperature of the Rankine cycle fluid entering the bottom of the TES is much lower than that of the heat transfer fluid in the case of the single heat exchanger. A parametric analysis to be completed by May, 1980 will hopefully confirm these expectations.

4. Upon completion of the computer model a reference design of a lowest cost TES system will be developed suitable for use in solar electric power generation.

Novel, alternative heat exchanger approaches are also being developed and soon to be demonstrated by the Naval Research Laboratory (NRL). The objective of the NRL effort is to construct, operate, and test a 10 foot diameter, 2 MWh demonstration energy storage tank using about 33 tons of eutectic salt. The site preparation and design of the facility are complete. The tank is scheduled for completion in the summer of 1980 with storage tests to be completed by the summer of 1981.

The basic energy storage boiler tank is shown in Figure 25. It consists of a large pressure-tight tank in which containers of salt eutectic are mounted on racks, largely filling the tank.

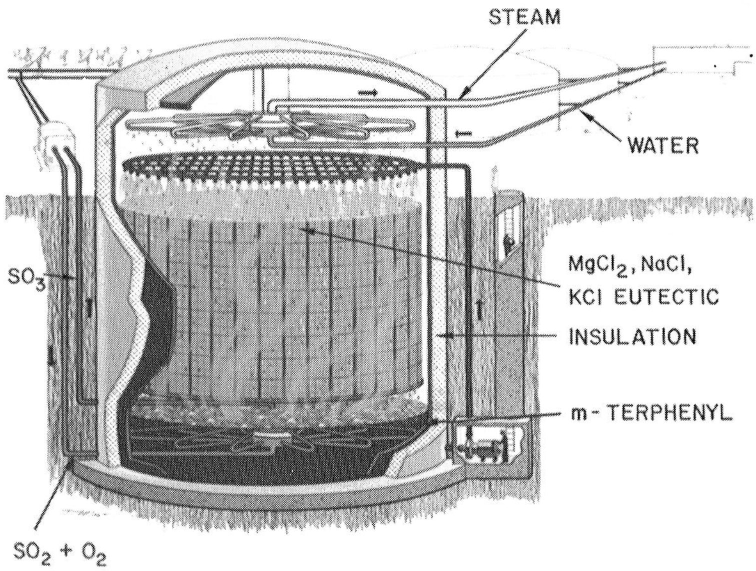


Figure 25. - Energy storage-boiler tank.

These containers provide a large aggregate area for heat transfer into the salts, which have low thermal conductivity. They also prevent the large volume change in the salt which occurs on freezing to result in large cumulative motion, such as would occur if the salt were stored in bulk.

The bottom of the tank contains the energy input region. As applied to a gas dissociation solar thermal power plant, energy input is effected by the chemical recombination of a work fluid, which results in production of heat. As adapted to a power tower, energy input would likely be provided by circulation of tower heated Na through the "heat release" tubes. In both cases heat energy is delivered to a pool of "heat pipe" fluid in the bottom of the tank, raising its temperature and boiling the fluid. The result is an increase in the pressure of heat pipe fluid vapor within the tank. Condensation of this vapor on the surface of the salt containers then delivers heat to the salt containers, melting the salt. Energy can be stored at nearly constant temperature until all the salt is melted. Further energy input results in a relatively rapid increase in tank temperature and pressure. When all the salt is melted, the full storage capacity of the tank has been utilized.

The remaining parts of the energy-storage boiler tank relate to energy withdrawal. First there are the boiler-superheater pipes, which are near the top of the tank. Heat is delivered to these pipes by condensation of heat pipe fluid, with energy transport limited largely by conductivity through the thin film of condensate which continuously forms and pours off the pipes. With this type of boiler, steam is produced in direct response to feed-water flow over a large range in demand.

Under no-sunlight conditions, operation of the boiler converts heat pipe fluid vapor into liquid, lowering the pressure of vapor within the tank. Replacement of this vapor is effected by evaporation of heat pipe liquid from the surfaces of the salt cans. To permit this process to continue until all the salts in the cans are frozen, it is necessary to keep the salt cans moist with liquid. A liquid circulation system is, therefore, provided to continuously pump liquid heat pipe fluid from the pool at the bottom of the tank and to spray the liquid over the salt containers. The surfaces of the containers are wetted by the heat pipe fluid facilitating full film coverage of the cans.

ACCOMPLISHMENTS

- Preliminary draft of multiyear program plan, (MYPP), for solar thermal applications released to private sector for information and comment - 4/79
- Cost and performance goals for large solar thermal electric power systems established - 4/79
- Submittal of SLL and SERI FY 80 annual operating plans to DOE for approval - 8/79
- Completed revised MYPP for DOE approval - 9/79
- Complete laboratory experiments of Honeywell active heat exchange concepts - 12/79
- Joint DOE/CST-STOR approval of MYPP - 1/80
- Held solar/storage program review - SERI action -2/80
- Recommended further development of active heat exchange concepts to DOE - 3/80

ISSUES

- None

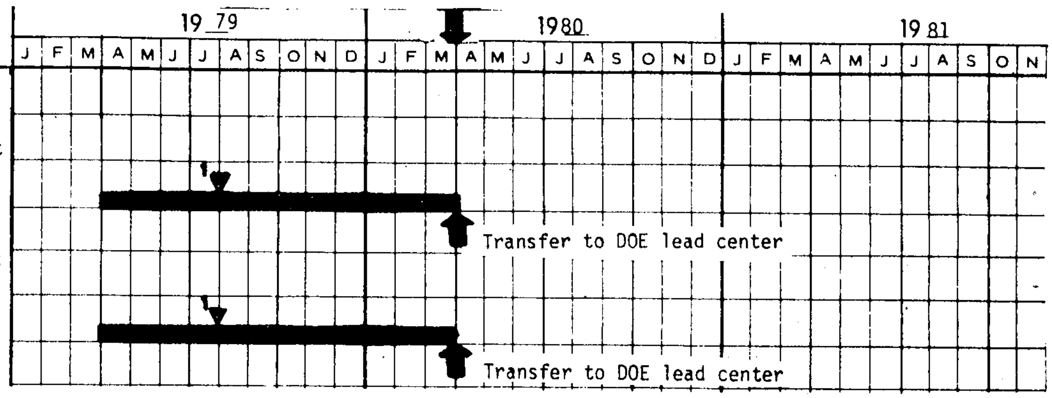
ACTIVITY SCHEDULE

ACTIVITY

4.1 PROGRAM MANAGEMENT

4.1.1 Technical and resource management of Solar Thermal Power Storage Application lead lab. activities

4.1.2 Technical and resource management of Solar Thermal Power Storage research lab. activities (SERI)



1. Lead lab AOP submittal to Lead Center

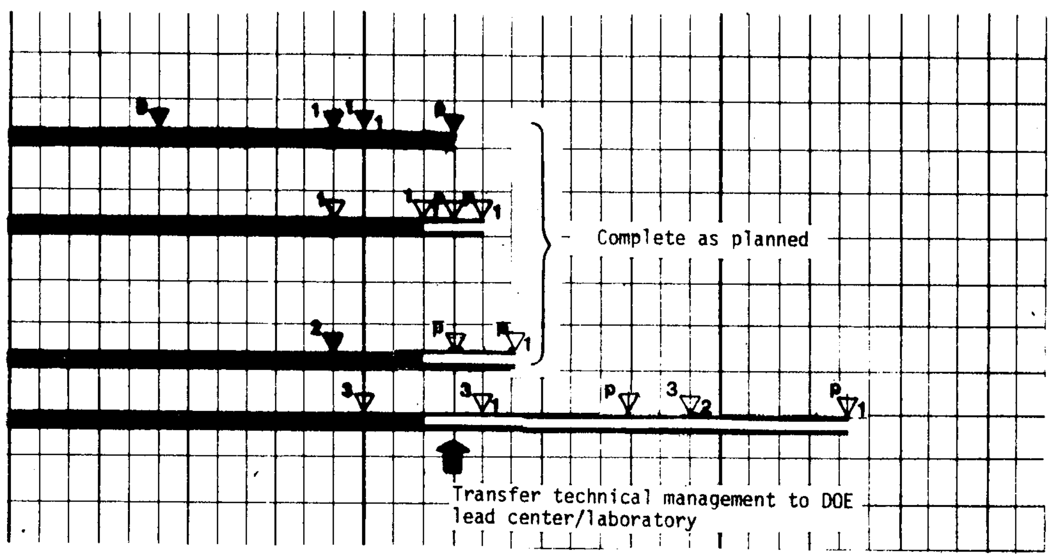
4.2 TES CONCEPTS DEVELOPMENT

4.2.1 Laboratory studies of active heat exchange systems (CP: Honeywell) DEN 3-38

4.2.2 Laboratory studies of active heat exchange systems (CP: Grumman) DEN 3-39

4.2.3 Laboratory studies of NaOH system for solar total energy applications (Comstock & Wescott) DEN 3-138

4.2.4 Fabrication of NRL energy storage boiler tank



1. Complete laboratory testing
2. Complete module evaluation
3. Complete fabrication and initiate operational tests

▽ Milestones
▽1 Rescheduled Activity
▼ Completed Activity
S Establish SEB
r Release RFP
a Award Contract
P Publish Report
SS Sole Source Procurement
CP Competitive Procurement
IAA Interagency Agreement
DHP DOE Headquarters Procurement
PA Planning Activity

5.0 BUILDING HEATING AND COOLING APPLICATION

BACKGROUND:

In its role as acting lead center, LeRC worked closely with ORNL in its lead laboratory capacity, to define a development and demonstration program for building heating and cooling applications. The objective of the program is to assess, develop and demonstrate improved and advanced thermal storage subsystems for residential and commercial heating and cooling applications. This activity provided for the technical and resource management of the lead laboratory efforts and the integration and coordination of this activity with other DOE storage tanks.

APPROACH:

In early May, 1979, LeRC and ORNL jointly formulated the guidelines on the direction of the project targets and goals. As previously noted, LeRC monitored the progress and provided information to ORNL to reach these targets and goals.

The overall program goal to be achieved by incorporating thermal energy storage into building heating and cooling systems is defined in terms of a single target: a reduction in oil and gas consumption for residential and commercial building space conditioning without a significant reduction in overall performance characteristics or comfort levels and without an increase in overall operating costs. The overall program will be achieved by establishing similar targets and achieving similar goals for each application element.

Goals for each application element are defined in term of three sets of specific targets: technology targets, economic targets, and market penetration/conservation targets. Establishing such targets and setting associated goals is a continuing process, wherein initial estimates are revised and redefined with increasing precision as the program moves toward implementation. In this first attempt at establishing targets and goals from building heating and cooling storage, the emphasis will be on target definition rather than goal setting. These targets will be used as a guide for a coordinated effort this fiscal year to develop the initial goals for each application element.

The following sections identify and define targets for each application element.

UTILITY LOAD MANAGEMENT TES APPLICATIONS

The overall target of thermal energy storage for utility load management is the reduction in consumption of oil and gas by increased shifting from peaking to baseload generation of electricity. This will be accomplished by means of customer-owned after-the-meter thermal energy storage sybsystems for both heating and cooling, charged during off-peak periods and used subsequently on demand during on-peak periods. The incentive for

installing such storage units will be a preferential rate structure offered by the utility and resulting directly from cost savings generated (simultaneously with the oil and gas savings) by the load management system. Because of inherent differences in utility load generation mix, customer composition, and other factors, implementation of customer-owner TES rates will be utility-specific with regard to the type, magnitude, and potential market penetration for the incentive rates offered. It should be noted that as many as 30 utilities are presently offering some form of incentive rates for TES residential customers, and most commercial rate schedules already include demand charges which serve as incentives for TES. However, there is already a wide divergence between utilities in both the type and magnitude of the incentive rate structure offered.

Specific targets for utility load management TES for which goals will be set include:

1. Technology targets (customer oriented)
    - o TES subsystems for various end-use applications
    - o performance and construction standards (ASHRAE, etc.)
    - o adaptability to different incentive rate structures and utility control strategies
2. Economic targets
    - o front-end cost of storage vs customer payback
    - o utility economic incentives
3. Conservation targets
    - o national conservation
    - o utility specific market penetration and conservation potential
    - o rate of penetration
    - o institutional incentives and barriers

SOLAR APPLICATIONS

The overall target of TES applied to solar building heating and cooling is oil and gas conservation by increased utilization of solar energy as a replacement for conventional (backup) fuels, including oil and gas. Thermal energy storage as a subsystem for a solar heating or cooling system (either passive or active) permits the use of solar energy when it is not being collected. The thermal storage subsystem thus increases the fraction of the building heating and cooling load capable of being met by solar energy alone.

The thermal storage subsystem is an integral part of a solar heating and cooling system such that there is a feedback between the cost and performance of the solar collection and utilization subsystems and the cost and performance of the storage subsystems. Thus, the potential conservation resulting from the utilization of TES with solar energy systems must be defined in terms of the entire system rather than the storage subsystem.

Specific targets for solar energy TES are defined as follows:

1. Technology targets

   - end-use application systems (active heat, active cool, passive)
   - "dual fuel" application systems
   - performance and construction standards
   - adaptability to different climates

2. Economic targets

   - system payback (entire solar energy system, including TES)
   - system payback with or without TES

3. Conservation targets

   - fractional reduction in backup fuel requirements (approach to all solar)
   - national market penetration/conservation
   - regional market penetration/conservation

DIRECT CONSERVATION APPLICATIONS

The primary goal of TES in direct conservation applications is conservation by reduction of fuel usage (including gas and oil) associated with operation of conventional systems for building space heating and cooling. Conservation applications include both use of TES incorporated within the building envelope to increase its overall thermal mass and TES to recover low-grade waste heat from conventional heating systems for later space heating use within the same building.

Conservation TES subsystems can be applied directly to individual conventional heating and cooling systems. They do not depend for their use on the development of new systems (i.e., solar) or external incentives (i.e., incentive rate structures).

Specific targets for direct conservation TES include:

1. Technology targets

   o end-use application systems (oil, gas, electric furnace, etc.)

   o performance and construction standards

2. Economic targets

   o subsystem paybacks

3. Conservation targets

   o fractional reduction in fuel usage

   o national market penetration

   o market penetration by end-use application

ACCOMPLISHMENTS:

o Reviewed FY 80 AOP by ORNL. Major thrusts are utility load management, solar space conditioning, and conservation (increased thermal mass) applications.

o Reviewed five-year plan for customer-owned thermal energy storage. Major elements included in the plan were:

   1. Storage in ice

   2. Storage using phase-change material (low temperature)

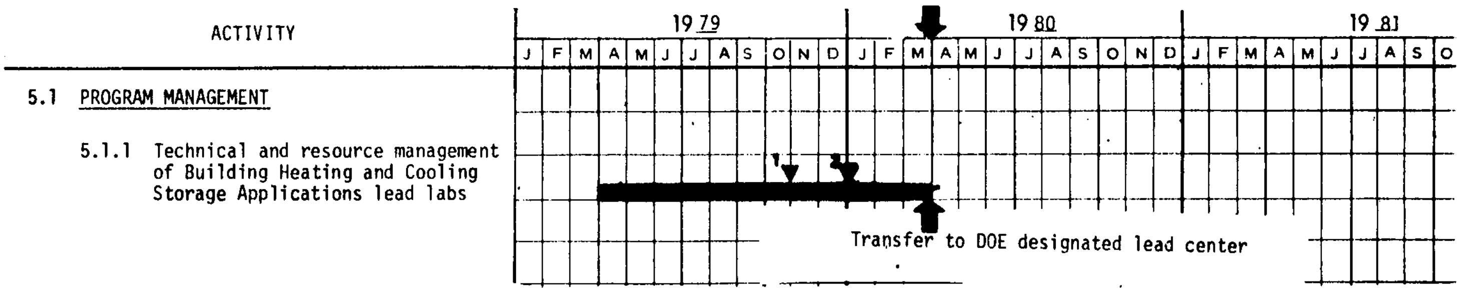
   3. Storage in ceramics (bricks) for high temperature

   4. Storage in water (low temperature)

ISSUES

None

ACTIVITY SCHEDULE



1. Lead lab AOP submittal to Lead Center
2. Management Implementation Plan approved

- ▽ Milestone
- ▽1 Rescheduled Activity
- ▼ Completed Activity
- S Establish SEB
- r Release RFP
- a Award Contract
- P Publish Report
- SS Sole Source Procurement
- CP Competitive Procurement
- IAA Interagency Agreement
- DHP DOE Headquarters Procurement
- PA Planning Activity

ACTIVITY SUMMARIES

CONTRACTOR	TITLE
General Electric Company Energy Systems & Technology Division Building No. 2-411 1 River Road Schenectady, NY 12345	Conceptual Design of Thermal Energy Storage Systems for Near-Term Electric Utility Applications (1.2) **CONTRACT NO.** DEN3-12
PRINCIPAL INVESTIGATOR	**PERIOD OF PERFORMANCE**
Eldon Hall	12-5-77 to 8-10-79
WORK LOCATION	**FISCAL YEAR FUNDING**
Schenectady, NY	349,014
CONTRACTING OFFICE	**CUMULATIVE FUNDING**
NASA-Lewis Research Center Cleveland, OH	358,733

BACKGROUND Studies of candidate utility energy storage systems, which were conducted by the Public Service Electric and Gas Company, Newark, New Jersey under ERDA Contract E(11-1)-2501 and EPRI Contract EM-264, identified thermal energy storage as a contender for early commercialization because of its technical and economic features.

OBJECTIVES The primary objectives of this study are to confirm the apparent attractiveness of thermal energy storage and to select and conceptually design the most promising systems for near-term utility applications.

APPROACH A comparative evaluation of candidate TES systems was conducted leading to the selection of four systems. Conceptual system designs of these systems in baseline plant designs were performed. Technoeconomic evaluations and operational characteristics were determined and a benefit analysis for each system was conducted. Development requirements were identified and demonstration program recommendations made.

OUTPUT The TES systems designed and costed in this study do not appear to be economically attractive for utility application. A significant cost reduction in the systems and operating costs is necessary to match the costs to that of gas turbines or cycling coal plants. The limited availability of TES systems, caused by a specific limit on hours of peaking capacity deliverable proved to be a disadvantage to some of the utilities simulated.

CONTRACTOR	TITLE
Midwest Research Institute 425 Volker Boulevard Kansas City, MO 64110	Assessment of TES Utilizing Fluidized Beds (2.3) **CONTRACT NO.** DEN 3-96
PRINCIPAL INVESTIGATOR Dr. K. P. Amanth	**PERIOD OF PERFORMANCE** January 79 to February 80
WORK LOCATION Kansas City, MO 64110	**FISCAL YEAR FUNDING** $99,000
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** 0

BACKGROUND Enhanced heat transfer for characteristics and solid particle mobility are two of many potential advantages of a fluidized bed storage system. In addition, the particle mobility eliminates the thermal stress limitation which is frequently encountered with either cored brick or pebble bed heaters.

OBJECTIVES To identify and analyze the operation, characteristics, and economics of potential thermal energy storage applications using fluidized bed heat exchangers.

APPROACH Identify potential fluidized bed concepts for thermal energy storage applications and perform a technoeconomic evaluation of selected heat exchanger/storage applications.

OUTPUT The assessment has been completed; however, the fluidized bed TES applications (electric arc furnace, cement kiln) were found to be marginally competitive for near-term baseline systems (Industrial Applications) based on present utility rate structure incentives. It was recommended that fluidized bed TES be assessed in further detail pertaining to Solar Thermal Power Applications.

CONTRACTOR	TITLE
University of Delaware Newark, DE 19711	Heat Storage in Alloy Transformation (2.4)
	CONTRACT NO. NSG 3184
PRINCIPAL INVESTIGATOR C. E. Birchenall	**PERIOD OF PERFORMANCE** July 1, 1978 to August 31, 1980
WORK LOCATION Newark, DE	**FISCAL YEAR FUNDING** $92,711
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $183,738

BACKGROUND This activity is one element of the Research and Technology Development portion of the TES program. The primary purpose of this activity is to identify and assess materials that have potential for use as media for advanced applications.

OBJECTIVES Determine feasibility of using eutectic metal alloys as thermal energy storage media for high temperature applications (650°C to 950°C).

APPROACH Survey alloy data to identify candidate alloys. Measure properties of candidate alloys including specific heat, latent heat, coefficient of expansion near the transformation temperature, and the volume change during transformation. Conduct media-containment material compatibility studies. Perform storage system analysis to compare performance and cost of systems using alloy and alternate media for selected applications.

OUTPUT Candidate alloys limited on the basis of cost to those that contain the following elements: Al, Cu, Mg, Si, Zn, CA and P. Several new ternary alloys have been identified in Cu-Si-Zn, Mg-Cu-Ca, and P-Cu-Zn systems. Specific heat and latent heat property measurements essentially complete. A new method employing x-ray absorption technique has been developed to measure volume change during phase transformation. Alloy media-containment material study was recently initiated to investiage three types of materials: graphite, silicon carbide, and surface-coated iron alloys. Thermal performance and cost estimation studies were initiated.

CONTRACTOR	TITLE
Institute of Gas Technology 3424 South State Street Chicago, IL 60616	High Temperature, Molten Salt-Latent Heat, Thermal Energy Storage Development for Solar Applications (2.5)
	CONTRACT NO. DEN 3-156
PRINCIPAL INVESTIGATOR T. D. Claar	**PERIOD OF PERFORMANCE** August 6, 1979 to August 5, 1980
WORK LOCATION Chicago, IL	**FISCAL YEAR FUNDING** $136,840
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $ 237,000

BACKGROUND This project is one element within the Research and Technology Development portion of the TES program. The primary purpose of this activity is to identify and assess materials that have potential for use as storage media for advanced applications.

OBJECTIVES Determine the feasibility of using carbonate salts as storage media for high temperature applications (700^{0} to $870^{0}C$)

APPROACH

- o Review carbonate salt properties and select six salts as candidate media.
- o Conduct carbonate salt-containment material compatibility studies that include 3000-hour screening tests.
- o Investigate methods to enhance heat transfer through solid salt.
- o Measure thermophysical and transport properties of two most promising salts.

OUTPUT

Review of properties complete with the following six salts selected for compatibility studies: three (3) pure carbonates, K_2CO_3, Li_2CO_3 and Na_2CO_3; two (2) eutectic mixtures, $BaCO_3/Na_2CO_3$ and $K_2CO_3/NaCO_3$, and one (1) off-eutectic mixture of Na_2CO_3/K_2CO_3.

Compatibility studies have been initiated and are due to be completed by mid-1980.

CONTRACTOR	TITLE
Lewis Research Center Thermal Storage Project Office 21000 Brookpark Road Cleveland, OH 44135	Engineering Evaluation of Thermal Energy Storage Modules (2.6) **CONTRACT NO.** EC-77-A-31-1034
PRINCIPAL INVESTIGATOR Richard Vernon	**PERIOD OF PERFORMANCE** FY 79 to June 1980
WORK LOCATION Cleveland, OH	**FISCAL YEAR FUNDING** $25,000
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING**

BACKGROUND This activity consists of subtasks performed in-house at LeRC which directly complement other project activities and provide supporting technology for new concepts and applications.

OBJECTIVES Evaluate prototype thermal energy storage modules to assess present state-of-the-art.

APPROACH Experimentally evaluate performance including factors such as: energy transfer rates to and from storage, heat loss, and long-term operational characteristics.

OUTPUT Completed initial evaluation of an electrically heated module that employs the solid-liquid phase change of NaOH and produces hot water. Electric heaters failed and are presently being modified for long-term testing.

Recently initiated evaluation tests of a dual media storage module that employs the solid-solid phase change of sodium sulfate and uses Therminol 66 as heat transfer fluid.

CONTRACTOR	TITLE
Howard Edde, Inc. 1402 140th Place NE Rockwood Office Park Bellevue, WA 98007	Collection and Dissemination of Thermal Energy Storage System Information for the Paper and Pulp Industry (3.4) **CONTRACT NO.** DEN 3- 190
PRINCIPAL INVESTIGATOR Dr. Howard Edde	**PERIOD OF PERFORMANCE** 15 Months Beginning February 5, 1980
WORK LOCATION Bellevue, WA	**FISCAL YEAR FUNDING** $113,816
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $113,816

BACKGROUND One of the industries showing the greatest potential for early implementation of TES systems was paper and pulp. The final report of the systems study of that industry indicated that adaptation of TES in 30 mills similar to the one studied in the report would save 3 x 10^6 bbl of oil per year by 1980.

Surveys of the industry have indicated that at least one paper and pulp mill in the U.S., and a number of mills in Europe and Scandinavia already employ TES in their mill processes. Extensive implementation of TES in the paper and pulp industry with attendant fuel conservation benefits will not occur unless effective information dissemination to the industry is obtained.

OBJECTIVES The objectives are to determine existing applications of TES in both the U.S. and international paper and pulp industries, to obtain and analyze the operating data from a representative number of these mills, and to transfer this information to the U.S. paper and pulp industry.

APPROACH

The contract requires the contractor to conduct a knowledgeable survey of both U.S. and international paper and pulp mills using thermal energy storage (TES) systems as a part of their production processes; to obtain from these mills, sufficient operating data to conduct a benefits analysis encompassing; (a) energy conservation assessment, (b) economic benefits analysis, and (c) environmental impact assessment; and propose an information dissemination plan using brochures, displays and presentations at paper and pulp industry technical and management meetings that will effectively present the benefits of TES to the U.S. paper and pulp industry.

OUTPUT

Since the contract was signed on February 5, 1980, the survey of the industry (Task I) has begun. All sub-contracts have been signed, with Snellman Engineering Company for the Scandanavian Survey; with EMC Inc. for brochure preparation; and with Aimex Corporation for display design and fabrication.

CONTRACTOR	TITLE
H. J. Heinz Company P. O. Box 57 Pittsburgh, PA 15230	Food Processing Demonstration (3.2)
	CONTRACT NO. TBD
PRINCIPAL INVESTIGATOR J. R. Inghram	**PERIOD OF PERFORMANCE** TBD
WORK LOCATION Pittsburgh, PA	**FISCAL YEAR FUNDING** -
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** -

BACKGROUND As a result of a DOE PRDA, Westinghouse, with Heinz as a subcontractor, identified several potential uses of thermal storage. This activity provides for an in-plant technology demonstration at the Heinz Pittsburgh facility. A hot water storage subsystem, which recovers thermal energy from hot water discharged after being used in the cooking process, will be designed, installed and operated.

OBJECTIVES To determine the economic viability and energy conservation potential of a thermal energy storage/waste heat recovery (TES/WHR) system in a food processing application.

APPROACH

Design, fabricate and install a Thermal Energy Storage/Waste Heat Recovery (TES/WHR) system in Heinz-USA, Pittsburgh facility.

Operate system to determine technical and operational features.

Determine economic benefits and energy conservation potential of system and effect technology transfer to the canning industry.

OUTPUT Negotiations have been delayed pending a resolution of ownership of installed equipment. System operation was expected to begin in early 1981, but will probably be delayed until late 1981. This activity will be coordinated with the National Food Processors Association to facilitate information dissemination.

CONTRACTOR TBD	**TITLE** Development and Technology Demonstration of Thermal Energy Storage (TES) Systems for Industrial Process and Reject Heat Applications (3.3)
	CONTRACT NO. TBD
PRINCIPAL INVESTIGATOR TBD	**PERIOD OF PERFORMANCE** 5 years
WORK LOCATION TBD	**FISCAL YEAR FUNDING** 500K
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** -

BACKGROUND DOE funded system studies have determined that attractive opportunities for thermal energy storage in-plant applications exist within the major energy consuming industries. These system applications have a sufficiently attractive return on investment to encourage widespread implementation once the technologies are developed and demonstrated.

OBJECTIVES The primary objectives of this project are to: contribute to the DOE goal of providing 10% of the U.S. industry's process heat or energy requirements by the year 2000 through TES; be cost effective by providing a return on investment that will attract broad scale implementation; be acceptable by the industry as being operationally safe and reliable; and be environmentally acceptable.

APPROACH A competitive two-phase procurement is in progress. Phase I will cover the preliminary design and analysis of the TES system and will also include component and subsystem development if required. Phase 2 will consist of a large-scale technology demonstration of the TES system in an in-plant application. Multiple awards are anticipated with cost sharing a requirement. Technology transfer will also be an important part of each contract.

OUTPUT The effort will result in operational TES systems at Industrial Participant's sites with the system design and data available to all of the industry.

CONTRACTOR	TITLE
Honeywell, Inc. Energy Resources Center 2600 Ridgeway Parkway Minneapolis, MN 55413	Active Heat Exchange System Development for Latent Heat Thermal Energy Storage (4.2.1) **CONTRACT NO.** DEN 3-38
PRINCIPAL INVESTIGATOR Richard T. LeFrois	**PERIOD OF PERFORMANCE** May 22, 1978 - November 21, 1979
WORK LOCATION Minneapolis, MN	**FISCAL YEAR FUNDING** $93,160
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $328,701

BACKGROUND A major problem associated with utilization of the heat of fusion of molten salts is accumulation of salt deposits on discharge tube surfaces. This imposes a large heat exchanger surface area requirement. To minimize a potentially large capital investment in required heat exchangers, concepts have been proposed which actively inhibit or remove salt depositions from discharge tube surfaces.

OBJECTIVES Develop an active heat exchange system, utilizing a phase change thermal storage medium, where operating characteristics are compatible with a 250° to 350°C steam power cycle.

APPROACH

- o Identify and select concepts for test
- o Design, fabricate, assemble and test laboratory-scale modules
- o Evaluate results
- o Recommend further development requirements

OUTPUT Two active heat exchange concepts were identified, designed, fabricated and tested in laboratory experiments. The Coated Tube Flowby Experiment is based on coating discharge tube surfaces with anti-stick materials such as nickel, chrome, Teflon, or Ryton. The Direct Contact Reflux Boiler is based on the injection of high pressure, high temperature water directly into the salt melt, vaporizing the water as the salt freezes, and then condensing on discharge tube surfaces.

Tests using an electroless nickel coating in the Coated Tube Flowby Experiment confirmed that salt adhesion still had a deleterious effect on heat transfer - to an extent which did not warrant further consideration. The Reflux Boiler experienced severe salt hydrolysis, compounded by an irreversible chemical reaction of nitric acid with the container walls. As a result, only half the design steam pressure could be achieved.

CONTRACTOR	TITLE
Grumman Aerospace Corporation Bethpage, NY 11714	Active Heat Exchange System Development for Latent Heat Thermal Energy Storage (4.2.2)
	CONTRACT NO. DEN 3-39
PRINCIPAL INVESTIGATOR Joseph Alario	**PERIOD OF PERFORMANCE** June 13, 1978 - April 12, 1980
WORK LOCATION Bethpage, NY	**FISCAL YEAR FUNDING** $40,872
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $264,502

BACKGROUND A major problem associated with utilization of the heat of fusion of molten salts is accumulation of salt deposits on discharge tube surfaces. This imposes a large heat exchanger surface requirement. To minimize a potentially large capital investment in required heat exchangers, concepts have been proposed which actively inhibit or remove salt depositions from discharge tube surfaces.

OBJECTIVES Develop an active heat exchange system, utilizing a phase change thermal storage medium, where operating characteristics are compatible with a 250^{o} to $350^{o}C$ steam power cycle.

APPROACH

- o Identify and select concepts for test
- o Design, fabricate, assemble and test laboratory-scale modules
- o Evaluate results
- o Recommend further development requirements

OUTPUT Two active heat exchange concepts were identified, designed and fabricated. Tests are in progress. In the first concept, called the Direct Contact Heat Exchanger, separate streams of salt and a liquid metal heat transfer fluid are mixed together in a heat exchange column, where, upon discharge, both latent and sensible heat are transferred to the cooler liquid metal by a countercurrent flow of molten salt droplets injected at the bottom of the column, As the salt rises it is directed over the top of the column to a surrounding tank.

The second test module, called a Rotating Drum Scraper, uses the same salt storage medium and liquid metal heat transport fluid. During the discharge cycle, molten salt flows through slit nozzles onto the circumference of a rotating drum. After the drum has made a partial (270^{o}) rotation, the solidified layer of salt is scraped off with a fixed scraper blade.

CONTRACTOR	TITLE
Naval Research Laboratory	Heat of Fusion Energy Storage Boiler Tank (4.2.4)
	CONTRACT NO. EC-77-A-31-1024.M003
PRINCIPAL INVESTIGATOR T. A. Chubb	**PERIOD OF PERFORMANCE** July 22, 1976 to Oct. 1, 1980
WORK LOCATION 4555 Overlook Avenue, SW Washington, DC 20375	**FISCAL YEAR FUNDING** $100,000
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $360,000 by DOE/STOR $190,000 by NRL

BACKGROUND This activity is one element of the Research and Technology Development portion of the TES Program. The primary purpose of this activity is to demonstrate feasibility of an advanced concept that can be utilized in solar applications.

OBJECTIVES Demonstrate feasibility of heat-of-fusion energy storage-boiler tank.

APPROACH Evaluate media and heat transfer fluid properties and cycle life characteristics.

- Perform storage media-containment materials compatibility studies.
- Design, build, and operate a 2 MWh storage-boiler tank.

OUTPUT Completed property determinations and selected a eutectic salt (NaCl, KCl, Mg Cl_2) having a melting point of about 385°C, and M-terphenyl as the heat transfer fluid.

Compatibility studies are complete and mild steel containers have been selected.

Fabrication of 2 MWh storage-boiler tank is proceeding and scheduled to be completed in mid 1980. Operation and tests are scheduled through 1981.

CONTRACTOR Comstock & Wescott Incorporated 765 Concord Avenue Cambridge, MA 02238 Telephone: (617) 547-2580	**TITLE** Latent Heat (NaOH) Storage for Total Energy Systems (4.2.3) **CONTRACT NO.** DEN 3-138
PRINCIPAL INVESTIGATOR Richard Rice	**PERIOD OF PERFORMANCE** May 79 to April 80
WORK LOCATION Cambridge, MA	**FISCAL YEAR FUNDING** $92,500
CONTRACTING OFFICE NASA-Lewis Research Center Cleveland, OH	**CUMULATIVE FUNDING** $225,000

BACKGROUND

First Generation phase change storage systems are typified by using passive (no moving parts), tube intensive heat exchangers. The present contract with Comstock and Wescott is a continuation of a prior program which included the design, construction, and testing of an experimental one-tenth scale-model of a phase change thermal energy storage (TES) system suitable for use in electricity generating systems such as the Sandia Solar Total Energy Test Facility (SSTETF) at Albuquerque, New Mexico.

OBJECTIVES

To conduct laboratory scale testing of a modified anhydrous NaOH latent heat storage concept for small solar thermal power systems such as total energy systems utilizing organic Rankine systems.

APPROACH

Under a previous contract, NAS3-20615, a module was tested and a computer simulation code developed. This follow-on effort consists of diagnostic test on the module and investigation of alternative heat transfer fluids and heat exchange concepts.

OUTPUT

Post test analysis of the previously tested module indicated no internal corrosion or leakage. The module has been refilled with Thermkeep (91.8% Anhydrous NaOH, 8% $NaNO_3$, and 2% MnO_2) and prepared for a second test series using an alternative heat transfer fluid, Caloria HT-43. Silicone B was initially to be used; however, this fluid was found to be mildly reactive with the NaOH. The computer simulation model has been modified to predict the performance of this module in a solar total energy system environment. In addition, the computer model has been expanded to investigate parametrically the incorporation of a second heat exchange inside the TES module which will vaporize and superheat the Rankine cycle power fluid.

PUBLICATIONS

- O REPORTS
- O PRESENTATIONS

REPORTS

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15. Supplementary Notes

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16. Abstract

The DOE Division of Energy Storage Systems (DOE/STOR) is responsible for formulating and managing research and development in energy storage technology. Major responsibility for project management in selected areas has been shifted to the DOE national laboratories and other government agencies. NASA Lewis Research Center (LeRC) was given the primary responsibility for the development of high-temperature sensible and latent heat storage technology via Interagency Agreement EC-77-A31-1034. This annual report (January 1979-March 1980) was prepared as part of the reporting requirements under the respective Interagency Agreement noted above. This report describes not only the planning/implementation of activities associated with an "acting" lead center management role but also the technical accomplishments pertaining to high temperature thermal energy storage subsystems. Major elements reported are: 1.0 Program Definition and Assessment, 2.0 Research and Technology Development, 3.0 Industrial Storage Applications, 4.0 Solar Thermal Power Storage Applications, and 5.0 Building Heating and Cooling Applications.

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